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A better world with Quality!

Quality in the digital transformation

5th International Conference on Quality Engineering and Management

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FOREWORD

A warm welcome to everyone to the 5th International Conference on Quality Engineering and Management (ICQEM22)!

We are back again to an in person event! It is so great to see you all here at the University of Minho! I would like to deliver a special thanks to all of those that travelled from their home countries to Braga, in Portugal. I hope those that will attend online will have the chance to join us in person in the next edition in 2024.

This conference is an international forum to present and discuss the progress and recent evolutions in the fields of Quality Management, Quality Engineering and Organizational Excellence, thus providing a unique opportunity to share the latest insights of academic and industrial research and applications on these fields.

The International Conference on Quality Engineering and Management covers different topics related to Quality. In this 5th edition more than 100 proposals have been submitted and almost 90 were accepted for presentation, after revision by the Conference Scientific Committee. Papers accepted correspond to authors from all around the world, with 20 countries represented at this level. Therefore, a warm acknowledgment to all speakers, authors and Scientific Committee Members is well deserved – Thank You!

I would like to thank to all the four keynote speakers – Nicole Radziwill, Carlos Ribas, Josef Oehmen, Mareike Mohlmann – and to the master class trainers that were with us yesterday – Jorge Roman, Abdallah Obeikan, Saber Atiyeh and Khaled Hassan, these last three trainers coming from the Obeikan Group located in the Kingdom of Saudi Arabia. We have here the chance to listen to their contributions and new development insights, and to network with some of the most current influent Quality Academicians and Professionals.

Finally, I must acknowledge the institutional support received from the School of Engineering of the University of Minho, Research Group on Quality and Organizational Excellence, ASQ University of Minho Student Branch, TecMinho, ALGORTIMI Research Centre, University of Coimbra, University of Girona, International University of Catalunya, European Organization for Quality, Portuguese Association for Quality, Brazilian Association of Production Engineering, Quality for Excellence Consultancy, International Journal of Conformity Assessment and Brazilian Society for Quality and Excellence in Management.

Last but not the least, a special thanks to all the members of the Organizing Committee and Co-Founders of the conference that make this conference possible for the 5th time.

Let’s take advantage of this great opportunity and make with your contributions an event with High Level of Quality, shared and built by such a top level group of attendees, thus contributing to “A better world with Quality!”.

Enjoy the conference and the beautiful city of Braga! Thank you!

University of Minho, July 13, 2022.

Conference Chair
Paulo Sampaio, University of Minho

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In Memoriam of Professor Mohamed Zairi

Please find below one of the last contributions of Professor Mohamed Zairi.

Quality 4.0 – Why Digital is its Identity?

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Why quality as we know it needs revisiting.

Product orientation has in fact been superseded by a significant focus on services and even service orientation has been superseded by customer orientation, where the emphasis on customer experience has become the norm. Furthermore, customer orientation is now being superseded by market orientation, where business models themselves are being redefined to adapt to significant changes taking place, particularly through disruptive technologies in the form of smart mobile and the advent of the internet. Quality that impacted over a century, has largely focused on products and services in terms of developing them, improving manufacturing or production processes, and expediting delivery to the end customer. The value created was largely related to product physical attributes related to functionality, with a focus on reliability and durability aspects. The focus was concerned with minimising variation, optimising performance, tackling costs through lean and Six Sigma principles.

The following twelve major impediments are preventing the quality profession from playing its dual role in a modern business context. There is an urgent need to create a new focus with fresh ideas and modern philosophies. Or perhaps, to make adaptation relevant as opposed to superimposing all thinking, all philosophies, tools, and techniques conceived and implemented in the context of a product-oriented era into a new emerging era of customer experience management and market orientation.

1. The pursuit of imperfection in an age of mass commoditisation. How can we prevent quality management from tackling deficiencies, variation, and suboptimisation when the mindset of the customer is to treat everything as a commodity, and where imperfections that were the main focus in the past, are no longer a major concern to customers who indulge, consume and look for replenishment?

2. Obsession with optimisation rather than radicalisation. In line with the previous point, would it be appropriate for the quality profession to focus entirely on the design of processes and their optimisation for squeezing out more benefits and generating value to the customer, supposedly by reducing costs, whilst the real requirement is to reconfigure processes, redesign, reengineer, and look at the value proposition concerned from a radicalised perspective, particularly by embedding smart technologies?

3. The emphasis on consistency rather than disruption. By 'stabilising the ship' and using the plan, do, check, act philosophy of minimising variation, optimising, and creating value through consistency, wouldn't this worthwhile exercise distract from focusing on radical innovations through the disruption aided by the digital mindset and new technologies?

4. The rigid discipline of compliance rather than the mindset of catalyst and contriver. In this context, quality of compliance is not the norm it is now a minor subset. What is required is more emphasis on creativity, innovation and disruptive thought processes that look at synergy, the blending of ideas, co-creation and collaboration for delivering value in a much better way.

5. Concern with the resistance to change as opposed to managing change proactively. In an era of high disruption fuelled by digital technologies, change has become a source of strength that can be used to adapt, to respond with speed, flexibility, and agility, and reach out to the winning line with much bigger and more significant impact.

6. The isolation of customers from value creation activity. This is a critical point where a departure from product orientation is urgently needed, as, in the context of the customer experience management era, the customer is truly in the driving seat and value creation activity from a personalised point of view is what matters. The days of mass production and mass delivery are gradually disappearing forever.

7. The inability to redefine value in an experience-oriented context. looking at value creation as a simple formula, by focusing on benefit and cost as the only parameters, can be limiting. However, the experience management context looks at the value from the emotional perspective of the customer and, therefore, benefit is not necessarily the tangible measurement. Emotional impact is the new real way of looking at value and generating customer satisfaction and happiness is becoming the main goal.

8. A narrow-minded view of customer satisfaction measurement. This is an extremely limiting factor. Many organisations have tried to dilute the importance of customer satisfaction measurement by adding some real-time exit measurements in the context of services: the concept of the mystery shopper and the use of social media to allow one-to-one interviews and evaluations of customer experiences. Whilst this is a more accurate way of assessing customer satisfaction, nonetheless, new tools and techniques are required for looking at the emotional aspects of satisfaction and, therefore, the trigger mechanisms for generating true happiness and total loyalty.

9. The myopic consideration of competitiveness factors. In the digital era, it is more and more recognised that intangible assets are the real measure of an organisation’s net worth and, therefore, its value to its stakeholders. The intangible assets include the structural, informational, the cumulative know-how, the customer network and the intelligence generated through big data, for example. These are what make the decision-making process in organisations more accurate, better focused, and significantly more impactful.

10. The pull adaptation of concepts, principles, and tools in the context of the new industrial revolution. The new industrial revolution fuelled by smart devices provides an ideal opportunity to create new business models by building synergies that did not exist previously. For example, being connected to supplier networks, the customer networks and society at large is a way of creating an open system where an organisation can, through its connectedness, make better decisions, have real time feedback, and ensure it steers its strategy in the right direction for achieving the right impact. New tools and methods have been developed for generating better customer insight and with the opportunity to proactively engage customers in new product development through concepts such as collaboration and co-creation.

11. The rise of emotional (happiness) orientation in quality measurement. There are various tools and techniques being pioneered now to extend the concept of value creation and measure the impact on the customer from an emotional perspective. These are strongly associated with redefining the processes and the systems within the organisations so that they are more customer centric, and so that customer experience management is really the umbilical cord for delivering value to the end customers.

12. Agility and the definition of quality management as we know it. Consistency, control, and predictability are classical concepts that have enabled businesses and government sector organisations to thrive and build superior standards of competitiveness through the net contributions that the quality profession has made over the years. However, in an uncertain world of radical change, where disruptive technologies are reshaping and redefining the macro and micro elements of doing business, the requirement is no longer for control and consistency, but on developing a capability that can be referred to as agility. Not just from the point of view of strategic management, but also in terms of creating a business model that can reconfigure itself, recreate and renew itself, so that it remains relevant to the customers and to compete effectively.

The New Quality Revolution (Quality 4.0)

The existing quality principles, philosophies, tools, and concepts that have worked so well for the 20th century, through delivering constant economic growth and improved the standards of billions of people for over 100 years, may no longer be sufficient and applicable in the digital era. The new digital world is one which explores limitless possibilities, focuses on organization as open dynamic systems and value creation has been redefined and is driven by collaboration, co-creation and leveraging through connectivity. In this instance, the new era can be characterized by constant disruption as opposed to predictable organizational behaviour, relevance has become more important as opposed to a focus on longevity and value has become the 'currency' of competitiveness rather than 'tangible' means based on products and services. What is proposed is a new model, a new approach for creating a new DNA for Quality that is fit for the new purpose. The following sections will present a proposed model for the new quality revolution and the elements (nucleotides) which form the basis for creating the new DNA (Figure 1). These are the structural arrangements for the definition of what Quality 4.0 is all about.

The Propelling Force – Discovery

Quality Management, in its conventional sense and as advocated by all the quality gurus, has been to identify the needs and requirements of customers and translate those into tangible and intangible value-added contributions that are then transferred to the customer, and for which the customer is expected to pay a premium price acceptable to them, but more importantly, that can bring back commercial benefits to the provider organisation. However, in the context of Quality 4.0, the identification of needs and expectations and specific requirements will not serve any real purpose. This approach has become a limiting approach. In the era of mass personalisation, value creation works through an open system perspective, defined by a nomenclature of atomised and integrated value creation energies and linkages of which the customer is one of the key stakeholders using the concept of co-creation.

In this context, the starting point is a capability that has been referred to as discovery, which is about understanding patterns, behaviours, evolutions, examples, technological opportunities and the dynamic aspects that define the macro market environment. In addition, the characteristics of a new generation of customers, such as the millennials generation and generation Z, can be 'disruptors' in terms of their expectations. A discovery capability is a source of inspiration, the creation of a knowledge reservoir that gives immense possibilities through permutation, through evaluation, through integration and through manipulation of thought processes that can help as raw material for the journey of understanding the requirements of personalised, customised, fulfilling experiences, and what is called to the value creation requirement.

Discovery, is an open-ended process without judging, restricting, analysing and decision making. It is more for understanding, creating good awareness and being aware of all the emerging concepts, the new technological developments, the changes in behaviour, the moves, and smart actions of key competitors, etc. This capability is the trigger mechanism for creating a powerful engine of value creation with the capability of scaling up and delivering to the masses in an individualised, personalised way.

The Value Creation Generator

This set of nucleotide elements includes five distinctive aspects. It is concerned with the ability of a modern enterprise to create something that it can compete with, and to have the capability for replenishing and renewing the experiences that change in a radical manner, but by keeping the same standard of fulfilment and customer happiness.

1. Personalisation: the capability of a modern enterprise to be customer-centric, to offer the right set up and the right mindset and the opportunity for customers to be part and parcel of defining, designing, delivering, and consuming their own fulfilling experiences is something of immense power. By the same token, personalisation as a capability serves the masses with the agility, flexibility, and a capability of reconfiguring key elements of the experience journey to suit individual purposes and accomplish individual expectations at the highest level of fulfilment and joy made possible.

2. Perfection: quality is no longer fitness for purpose or meeting basic requirements. Quality is also not the pursuit of resolving customer unhappiness by dealing with complaints and tackling imperfections. Quality 4.0 is very much about perfection in doing things right first time, all the time, right from the onset, and not through iterations, changes and compromises. Perfection in the definition of requirements can only come through having co-creation as a powerful tool, and the involvement of customers as a stakeholder in the process. Furthermore, perfection is very much about prototyping, so a visual, tangible thing can give early feedback on likely reactions at the delivery stage, and therefore give the opportunity to realign the approach with emotional fulfilment in mind.

3. Partnership: innovating through customer experience in an open system for the purpose of unique and memorable experiences, and in the context of value creation will more and more depend on the connected world and using smart technologies. This will enable innovators to determine precisely where value ought to be created and what components can be managed internally within the leading innovator's grounds, and what other aspects can be added on by smart partners who are disruptors, pioneers and who can help create the notion of lots of one or personalised customer experiences. Partnership is not a linear process, as used to be the case in the conventional approach to quality management. It represents a network of connected key players in search of optimised value creation, and who define the boundaries of what is possible and who can bring in key capabilities for making personalised unique and fulfilling experiences, a reality.

4. Prediction: Prediction is what matters to the C-Suite and top executives. Big data enables organisations to safely contemplate the future with confidence and to predict patterns of behaviour and dynamics that can help with making the right decisions, allocating the resources in the right place, and delivering performance to the right level of ambition. This is a major departure from the previous quality mindset, where access to limited data made it impossible to build powerful predictive models and where management had to look at static reports with historical data sets. They had to guess what might or might not happen in the future or try to read between the lines in a desperate way by extrapolating and interpreting the data. In most cases, they would be partially or completely wrong in making decisions about the future.

5. Delivery: delivery of value in a modern business context is not necessarily about speed, location, logistics and fulfilment from the point of view of quality, of pledges made and charters, and so on and so forth. Delivery in a modern context is the emotional aspects and representing the desires of the customers in terms of selection of channels. In the future, there will be more talk about the use, for of omni-channels, where the customer defines their integrated environment and how and where the experience ought to be enjoyed and consumed. Delivery is also a process as opposed to a transaction. In this sense, it is based on the leading innovators' savviness in the exploitation of disruptive technology, but also in the impact of technology on the personalisation of the process, so that it addresses the specific needs, requirements and expectations and so that it targets the impact, not on the compliance to quality requirements or meeting expectations, but more on the emotional impact, in terms of the desired outcomes that the experience delivers, and which therefore helps in the value capture aspects by bringing back commercial benefits to the leading innovators and the associated network of partnerships.

The Business Renewal Rocket

Similarly, to value creation, business renewal is the power generation that fuels the needs and expectations from the point of view of personalised experience fulfilment perspectives, where the customer is concerned. The business renewal rocket is the element that can take off to demonstrate capability in going to bigger heights, exploring higher levels of ambitions, and redefining the landscape of competitiveness in the future, and the establishment of leading competitive positions. The ability of a leading innovator to constantly look at their Business Model Innovations (BMIs) and create capability for reconfiguring, rearranging and recreating capabilities to fulfil ever changing needs and requirements for personalised experiences. This is a daunting task and must be considered as the new pursuit of excellence or super excellence.

Figure 1: Nucleotides of the New Quality Revolution (Quality 4.0)

Experience: the era of experience means that innovation management as a stakeholder oriented process is a process which is dynamic, reconfigurable and where value creation is only relative in so far as customer experience stability is concerned. In a time of changing desires, expectations, wishes and ambitions from the customer base, the value creation will redefine permutations of the key elements and the key players and what preponderant role that can play in contributing to value creation and to the business model itself. An atomised structure through building a smart, integrated synergised connected network of partners doing regular transactions, sharing common capabilities, transferring knowledge and knowhow and having equal say in how value is created, for now and for the future, is indeed a powerful aspect of this rocket that can climb to bigger heights.

Engagement: the process that involves constant disruption, business transformation and the configuration of value creation for the end customer, needs a proactive way to manage talent and it is only through total engagement management that leading innovators have a chance to be effective in delivering the right value for the purpose of unique, memorable, individualised customer experiences. The engagement involves making real-time decisions, dealing with complex issues, being pre-emptive and feeling empowered to create on behalf of the customer. It is a complex process that puts human capital at the front end by executing their expert advice, skills and know-how, their ability to make speedy decisions on behalf of the customer.

Experimentation: In the digital era, customers will be deciding on the use of products and services in the wider context of their individualized experiences. Products and services will become 'means to an end'. Customers will decide on their shelf-life duration, the lifecycle of their repetitive potential. Since replenishment of memorable experiences is going to be the primary focus, value to the customer will constantly be re-evaluated. In most cases, experiences that are repeated will have a significant element of novelty thus making experimentation a core capability for provider organisations. It means having several options to choose from, having different alternatives for addressing unique and personalised experiences and looking at elements that may create the wow factor and trigger bigger emotional reactions in so far as customers are concerned. Experimentation in relation to individualised experiences, is looking at all the drivers, enablers, levers, and catalysts of customer experience, and how to capitalise on these ingredients in the context of specific needs and expectations and the personalisation aspects. This complex phenomenon requires internal and external interfaces, to trigger the dynamism of experimentation and exploration prior to execution. This will help create immense possibilities, and great opportunities for the leading innovators, who will deliver to their customers with confidence, with competence and with a capability for delivering a batch of one with limitless scalability.

Enlightenment: a modern enterprise which operates in a smart environment defined by disruptiveness and the capability to absorb large-scale change driven by digital technology, needs to be a learning organisation. It must operate on the basis that everything it does and everything it consumes must be treated with a relative state in mind. Knowledge is a commodity, systems invested in will have a short shelf life, and will be superseded by technological advancements. The shelf life of technology as an enabler will also shrink in terms of appropriateness and relevance, the techniques, tools, and concepts used will be subjected to a relative utilisation period and reassessed on the worthiness and appropriateness, as new opportunities emerge. Enlightenment is the confidence of doing new things, the competence of absorbing new complex methods, technologies, and approaches. This will lead to developing a capacity for change and absorbing new business mindsets with the same level of impact and the same ability to compete and deliver superior value to the end customer. This makes the concept of the learning organisation almost redundant because the criteria for being a learning organisation make the supposition that the organisation uses dynamism within its own shell by operating in a closed system format. Enlightenment is discovering for the sake of discovering, doing new things, learning through real-time feedback, and exploiting knowledge, which is transferred in real time mode, from a wide variety of stakeholders and partners, through being connected, and leaning on smart systems and the smart work environment. Enlightenment will lead to discovering new the possibilities for reconfiguring and reinventing of the existing BMIs.

Disruption: Building durable organizations was the focus in the 20th century. In fact, there are many texts with a title Building Business to Last and the pride and joy of founders of successful organisations such as Toyota, Ford, General Electric, etc. The previous focus was on building organisations that last, with the same ethos, inculcating the same organisational values, and propelling themselves forward with their ability to renew, to reinvent and to stay closer to their customers, and to induce growth that gives them the dominance through becoming globally successful. However, in the digital era, building things to last is not defined in the same way. Businesses operating in a modern context require a new DNA and have to have a shelf life in this context. Disruptiveness is really creating something new out of the old. It is to be current, to be meaningful, to be relevant and to be impactful. These are unprecedented conditions forced upon business leaders and caused by the spread of technology and the way it has changed the world and changed our lives.

Distinction: the competitive advantage for smart enterprises operating in a disruptive environment and fuelled by the possibilities that digital technology offers is based on the all the previous key elements. By harnessing the two pillars referred to as the value creation generator and the business renewal rocket, the dynamic behaviour of organizations boosted by quality 4.0 concepts can be put to work. Distinction is related to entirely new capabilities which will distinguish leading innovators from followers.

References

Zairi, M. (2017), Deep in Crisis: The Uncertain Future of the Quality Profession 1 st Edition, ECBPM Publishing House (UK)

SUBMITTED PAPERS

Analysis and Prioritization of Quality 4.0 dimensions and companies' readiness to adapt to industry 4.0 evolutions through Bayesian Best - Worst method

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Abstract

Introduction: The evolutions of the Fourth Industrial Revolution helped many companies and organizations to survive, achieving economic success and ensuring competitiveness, and has put them under pressure to align their goals, policies, strategies, and the nature of their operations with these changes. Therefore, the concept of quality and the nature of its operations to meet customers' needs in the digital era must be changed and updated in accordance with these developments. Quality 4.0 facilitates coordination between quality management and industry 4.0. A review of the literature shows that the concepts and perspectives of quality 4.0 have not yet evolved and matured, and therefore there is little research on the alignment of quality 4.0 management with industry 4.0 technologies.

Purpose: The main purpose of this study is to identify and evaluate quality 4.0 indicators to draw a roadmap for organizations to align quality 4.0 management with industry 4.0 technologies. **Methodology**: To achieve the goal, first the literature of quality 4.0, quality 4.0 management as well as industry 4.0 technologies were studied to gain a broad understanding of the subject. Then the dimensions and quality 4.0 indicators that are potentially affected by the implementation of Industry 4.0 are identified. Next, the importance and prioritization of dimensions and quality 4.0 indicators for alignment with Industry 4.0 using the Bayesian Best-Worst method are determined.

Findings: The research findings identify the dimensions and quality 4.0 indicators in different classes and then prioritize each of the indicators according to their importance in aligning quality 4.0 management with industry 4.0 technologies.

Conclusion: The results of this study help to facilitate the process of change management towards quality 4.0 in companies and outline a roadmap for companies to prioritize the nature of their operations regarding the changes and developments and the need for revision and provides investment in quality 4.0 management.

Keywords: Quality 4.0, Quality 4.0 Management, Change Management, Quality 4.0 Organizational Dimensions, Bayesian Best-Worst Method

Category: Research paper

Introduction

The development of the Fourth Industrial Revolution (FIR) enabled the connection between the digital and physical worlds and integrated individuals, devices and processes (Arsovski, 2019). This poses a significant challenge to the quality profession by emphasizing the need to adapt to technological innovations, modern data analysis, and the entrepreneurial ecosystem that characterized the Fourth Industrial Revolution (Zonnenshain and Kenett, 2020).

Quality 4.0 expanded as a response to production changes, both by digitizing quality management systems and by using digital tools to enhance productivity and quality of products Moreover, Quality 4.0 supports the digitization of management of quality, not only of products and technologies but also of processes and their cooperative integration with individuals. Another aspect that should be considered by Quality 4.0 is that the cost of technology has been decreasing over time, while the cost of labor increases over time. Therefore, to stay competitive in business, Quality 4.0 acceptance is inevitable (Yadav et al., 2021). However, understanding the various aspects and functions and implementing the tools of Industry 4.0 in diverse industrial environments continues to pose major challenges for academia and business alike. A review of the literature shows that the concepts and perspectives of Quality 4.0 have not yet evolved and hence there is little research on the alignment of quality management with Industry 4.0 technologies.

Given that the Industry 4.0 research literature is evolving rapidly and a great deal of conceptual and experimental work has taken place around the world over the past few years. However, research work, especially experimental work on Quality 4.0 is still evolving. Researchers believe that Quality 4.0 can be considered as a social and technical system. So far, the main tasks of quality management are process monitoring, and failures were controlled by in-process controls. However, due to advanced measurement technologies and advanced analytical capabilities, there is a shift in predicting and recognizing process conditions (changes in process performance) and understanding the quality performance characteristics that are important to customers and the company. Such a change helps us to measure and predict the system quality much sooner than those offered by traditional preventive quality assurance approaches. Such thinking is possible due to the emergence of big data, automation and data analytics. In this regard, the main purpose of this study is to identify the dimensions and quality 4.0 indicators in order to prepare companies to adapt to Industry 4.0 developments.

In this paper, the concept of Quality 4.0 is first examined. Then, various Quality 4.0 factors are presented to adapt the traditional quality management to the developments of the Fourth Industrial Revolution. In the methodology section, the importance of each of the Quality 4.0 factors is determined and finally, according to the priorities and the importance of Quality 4.0 factors, suggestions are presented for the studied industries.

Literature Review

Quality 4.0

The term Quality 4.0 is to pursue quality performance in the age of digital transformation. Quality 4.0 does not focus solely on technology, and other basic principles of quality such as people, processes, tools, techniques, methodologies, analytical thinking, etc. are an integral part of the current quality revolution. Quality 4.0 does not replace traditional quality methods, but is built and improved based on them.

Jacob (2017) states that the goal of Quality 4.0 is to prepare quality performance and play a leading role in the use of I4.0 technologies to continuously deliver high quality products (Chiarini and Kumar, 2021, Jacob, 2017). Quality 4.0 provides industry-leading quality, framework, and language leaders to reap the benefits of step-by-step performance that extends across the entire value chain, including consumers, customers, field services, logistics, manufacturing, engineering, R&D, and suppliers (Chiarini and Kumar, 2021). According Sony et al. (2020), under the Quality 4.0 concept, digital tools may be used to improve the ability of organizations to consistently deliver high quality products (Sony et al., 2021). Chiarini and Kumar (2021) attempted to explain the concept of Quality 4.0 using an exploratory method. Based on their findings, a theoretical model for Quality 4.0 was proposed that included eleven Quality 4.0 topics in three categories - people, process and technology. These topics include model development, top management, process mapping, data collection and integration with enterprise resource planning systems, use of artificial intelligence software, machine-to-machine data communications, product identification and traceability, document control and skills digital for quality control staff. In general, the evolution of quality concepts in accordance with the evolution of the Industrial Revolution in different periods is shown in Table 1.

Table 1- The evolution of quality concepts in relation to the Industrial Revolution (Sader et al., 2021)

Evolution	**Industry 1.0**	**Industry 2.0**	**Industry 3.0**	**Industry 4.0**
Product	Steam Age - Mechanical Production Systems	The Age of Electricity - Mass Production	Information Age - ICT and Automation Systems	The Age of Cyber Physical Systems - Mass Customization
Quality	Quality control - inspection	Quality Assurance	Total Quality Management	Quality responsibility - open quality

There are five main motivations for implementing Quality 4.0 in organizations (Sader et al., 2021): (1) reliable information, (2) big data to drive quality applications, (3) improving customer satisfaction, (4) improving productivity and (5) long-term savings.

Quality 4.0 Management

With globalization and industrialization, meeting customer expectations is constantly increasing, and the pressure on organizations to provide high quality products and services on time and at a lower cost to maintain its position in the market is increasing day by day (Antony et al., 2021a). In such situations, Quality Management (QM) seeks to optimize processes and maintain the quality of products or services and further develop them (Hehenberger, 2011).

Quality management is an essential basis for companies due to increasing expectations of customers, market competition and is therefore part of the company's goals, strategies and policies (Zonnenshain and Kenett, 2020). With the advent of I4.0, quality management has evolved through the use of digital technologies related to external or internal data networks (Dias et al., 2021). Industry 4.0 tools can help increase the quality of production processes, such as the quality of information needed for optimization, planning and operation, the quality of forecasting, simulation and prototyping, and better employee participation (Godina and Matias 2018). Quality 4.0 refers to the digitalization of quality management in the Industry 4.0, and different perspectives must be considered in order to enable decisive implementation and thus monitor the progress of the production environment towards the acquisition of new technologies (Jamkhaneh et al., 2021). Thus, proper quality management, based on industry-based processes and technologies, facilitates product development, reduces failure, and increases customer satisfaction (Glogovac et al., 2022).

Quality 4.0 criteria and dimensions

Quality 4.0 is a novel approach to manage quality where digital tools enhance the organization's ability to consistently deliver high-performance products to customers (Küpper et al., 2019). Even employee readiness to comply with the quality management program in Industry 4.0 has become a common theme in research circles (Gunasekaran et al., 2019). Research by Küpper et al. (2019) found that one-third of the 221 manufacturing companies knew how to digitize the skills and plans of quality management, and seventeen percent thought their factory had the right people to implement the Quality 4.0 plan. Five main barriers for implementing Q4.0 are: lack of digital skills and talents, lack of uncertain digital strategy and culture, outdated infrastructure and dispersion of quality data. Krubasik et al. (2015) found that the use of quality methods in I4.0 is low (27%), but the majority of respondents (73%) believe Q4.0 benefits of innovative quality. In a study by Jacob (2017) 11 axes consist of: (1) Data, (2) Analysis, (3) Connectivity, (4) Collaboration, (5) Application development, (6) Scalability, (7) Management system, (8) Compliance, (9) Culture, (10) Leadership, and (11) Competence. Radziwill (2018) argued that quality professionals should lead the transformation from the classical perspective to Quality 4.0. Required skills are: A) Systemic thinking, B) Data-based decision making; C) Leadership for organizational learning, D) Creating processes for continuous improvement; E) Understand how decisions affect individuals: life, relationships, communities, welfare, health and society in general.

Kwon et al. (2014) presented big data analytics as an innovative information technology capability and a strategic resource that can create a competitive advantage for a host company. Given this situation, they examined the dynamics between data quality management at the company level and its impact on data use and the intention to accept big data analysis. Janssen et al. (2020) provides a conceptual framework for the adoption of China blockchain technology that depicts the complex relationships between institutional, market and technical factors. Their findings show that the factors presented in the framework (institutional, market and technical) interact with each other and affect each other. Adoption of advanced technologies can be more challenging for emerging countries (Kumar and Siddharthan 2013). Factors such as ICT infrastructure, culture, level of education, and economic and political instability can also play a role in perceiving value and thus the level of investment in advanced technologies (Frank et al., 2016). Dalenogare et al. (2018) in a study analyzed the benefits of development of product, operations and aspects of the expected side effects of an industry to implement I4.0 technologies. They found that only some of them are beneficial for the industry. Frank et al. (2015) believe that there are three socio-technical dimensions to technology to consider the process of digitalization in order to implement the Industry 4.0, which are: work organization, human factors and external environment. Gunasekaran et al. (2019) sought to explore quality improvements and their implications for economics, decision-making models, business models, human perspectives, and technology, and future research paths such as the importance of human issues in quality management in line with the industrial revolution and alignment. Determine the technological revolution over time and the involvement of human aspects in quality management.

Dovleac (2021) Research focuses on providing knowledge management practices for companies seeking Quality 4.0 acceptance to ensure that these companies use relevant data in their day-to-day operations. In other words, identifying relevant data and ways to manage it is considered as a major obstacle in implementing Quality 4.0 practices. Sony et al. (2020) believes that one of the key components of Quality 4.0 is the integration and use of data, as well as knowledge, to improve design quality, quality of compliance and performance quality, and to optimize activities in a company. Another key aspect of Quality 4.0 is senior management support and the selection of current training tools and modules that apply to companies that are seeking to integrate Quality 4.0. Sony et al. (2021) used online surveys of experts in top companies in Europe and the United States to examine the motivations, readiness, and barriers factors for Quality 4.0 implementation. Their findings show that five motivational factors, as well as barriers and readiness for Quality 4.0 were identified and then ranked in order of importance.

According to the literature, research by Jacob (2017) is one of the most comprehensive research that has identified indicators and effective factors in adapting the traditional quality management system to the developments of the FIR and is the main basis of this study. An overview of the literature review is shown in Table 2.

Table 2- An overview of the literature review

Cod	**Dimensions of Quality 4.0**	1	2	3	4	5	6	7	8	9	10	11	12	13	14	Present study
C1	Data	●	●	●		●	●	●	●	●	●	●	●			●
C2	Analytics	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
C3	Connectivity	●		●		●		●			●		●	●	●	●
C4	Collaboration	●	●		●	●		●	●	●	●	●	●		●	●
C5	App development	●				●										●
C6	Scalability	●				●	●	●	●	●	●		●	●	●	●
C7	Management system	●	●	●	●	●		●	●			●	●		●	●
C8	Compliance	●			●	●	●			●	●	●	●		●	●
C9	Culture	●	●	●	●	●	●	●		●		●	●	●	●	●
C10	Leadership	●	●		●	●			●	●		●		●	●	●
C11	Competence	●	●			●	●		●	●	●	●		●	●	●

1.Alzahrani et al. (2021) 2.Antony et al. (2021b) 3.Dias et al. (2021) 4.Glogovac et al. (2022) 5.Jacob (2017) 6.Sader et al. (2021) 7.Sony et al. (2021) 8.Sureshchandar (2021) 9.Yadav et al. (2021) 10.Zonnenshain and Kenett (2020) 11.Chiarini and Kumar (2021) 12.Gunasekaran et al. (2019) 13.Foidl and Felderer (2015) 14.Fonseca et al. (2021)

Methodology

The present work is an applied and descriptive-analytical research study. To identify the dimensions, the library method was used and research information and data were collected through the distribution of questionnaires among managers and experts in the studied industries. According to the purpose of the research, first, by reviewing the literature, dimensions and Quality 4.0 indicators were identified. Then, a questionnaire for pairwise comparisons was prepared and provided to the experts, and finally, the importance of dimensions was determined using the Bayesian Best-Worst Method (BWM). BWM is one of the approaches to evaluate the weight of indicators and options based on pairwise comparisons developed by Rezaei (2015). The basis of this technique is the division of pairwise comparisons into two parts, main and secondary comparisons. When evaluating, experts generally consider one option as the best and the other as the worst, and compare the other options to the two. In this case, the main comparison is formed. When the best and worst options are not selected and comparisons are made, a sub-comparison is made. In this technique, only the main comparisons are made and there is no need for sub-comparisons. Accordingly, experts should make fewer comparisons, thus increasing accuracy and speeding up the decision-making process (Rezaei, 2016). Also, by reducing the number of comparisons, data collection is done more easily and accurately and the rate of inconsistency in comparisons is reduced.

The best-worst method has five steps as follows:

Step 1: Determine the set of decision criteria

Step 2: Determine the best and worst criteria

Step 3: Select the best criterion and prioritize the best criterion over other criteria: For this purpose, a comparison is made using a number between 1 and 9. The more important this criterion is than other criteria, the greater the number we attribute to it. The result is the best vector (BO), which indicates the priority of the best criterion (B) over the criterion j ($A_B = a_{Bj} \{a_{B1}, a_{B2}, ..., a_{Bn}\}$).

Step 4: Select the worst criterion and determine the priority of all criteria on the worst criterion: for this purpose, the worst criterion is selected and then the importance of other criteria to the worst criterion is determined by numbers 1 to 9. The result is the worst vector (WO), which indicates the priority of criterion (j) over the worst criterion (W) ($A_w = a_{wi} (a_{w1}, a_{w2}, ..., a_{wn})^T$).

Step 5: Determining the optimal weight: In this step, the optimal weight of the criteria is obtained. The weight of the criteria is obtained using the following model in such a way that the difference between all the criteria is reduced:

$$\min-\max_j = \left\{ \left| \frac{w_B}{W_j} - a_{Bj} \right|, \left| \frac{w_j}{W_B} - a_{jw} \right| \right\}$$

$$\sum w_j = 1 \qquad ,w_j \geq 0 \ , \forall \ j$$

To solve this problem, linear programming can be changed as follows:

$$w^{\alpha gg}$$

Bayesian best-worst method:

This method is a hierarchical model for finding the priority of criteria according to the following figure, the application and development of which requires the identification of independence and conditional independence between variables (Mohammadi and Rezaei, 2020).

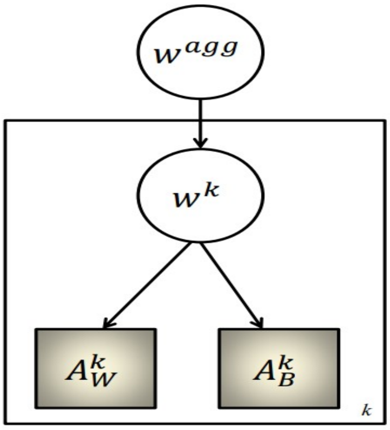

Figure 1- The probabilistic graphical model of the Bayesian BWM (Mohammadi and Rezaei, 2020)

In Figure 1, the nodes represent the variables to be estimated and the rectangles represent the observed variables that are the main inputs of this model. Arrows also indicate the connection node and that the node is originally dependent on the node at the other end. Accordingly, the value of w_k depends on A_w^k and A_B^k the value of $w^{\alpha gg}$ depends on w_k. This figure, which contains a set of variables, means that the corresponding variables are repeated for each decision. Since there is only one decision to make for $w^{\alpha gg}$, $w^{\alpha gg}$ is out of the page. Conditional independence between variables can also be extracted based on this figure. For example, A_B^k dependents on w_k and $w^{\alpha gg}$ being itself dependent; therefore:

$$P\left(A_w^k \middle| w^{\alpha gg}, w^k\right) = \left(A_w^k \middle| w^k\right)$$

Taking into account all the independence relations between the different variables, the Bayesian rule is written as follows:

$$P\left(w^{\alpha gg}, w^{1:k} \middle| A_B^{1:k}, A_w^{1:k}\right) \alpha \ \mathrm{P}\left(\left|A_B^{1:k}, A_w^{1:k}\right| w^{\alpha gg}, w^{1:k}\right) P\left(w^{\alpha gg}, w^{1:k}\right)$$
$$= \mathrm{P}\left(w^{\alpha gg}\right) \prod_{k=1}^{K} P\left(A_w^k \middle| w^k\right) P\left(A_B^k \middle| w^k\right) P\left(w^k w^{\alpha gg}\right)$$

Accordingly, the last equation is created using the rule of probability chain and conditional independence between different variables and indicates that each decision maker expresses his priorities. Since the estimation of the parameters in the above relation depends on the estimation of other variables, it can be said that there is a chain between different parameters, hence this model is called hierarchical.

In this study, the necessary information was collected through a survey of researchers and a questionnaire. As mentioned, this research seeks to examine the dimensions of Quality 4.0 in order to prepare companies to adapt to the developments of industry 4.0 in the Energy, Food and Shipbuilding industries. Therefore, using purposive sampling method, 15 experts and quality managers in these industries who had at least 10 years of experience were interviewed.

Findings

In this study and after reviewing the literature on the subject of basic criteria (see Table 2), Quality 4.0 criteria were identified in order to prepare companies to adapt to industry developments. Then, these criteria were provided to the experts and after review, they were finalized in Table 3.

Table 3- Identify and localize Quality 4.0 criteria using expert opinions

Criteria	Symbol	Definition
Data	C1	Ability of the organization to record, store, analyze, identify trends and patterns in the big data and data from the organization's processes and operations
Analytics	C2	Applying various approaches and methods to analyze the business in order to cooperate in the decision-making process, increase organizational competitiveness, adopt customer-centered approaches and ...
Connectivity	C3	In the digital and industry 4.0 era, communication is very important and enables interaction between people, organizations, products, devices and processes.
Collaboration	C4	The increasing products, processes and technologies complexity has led to participatory partnership solutions and

		industrial collaboration to increase productivity. Also, according to the view of total quality management, there is a need for participation and cooperation of all employees at different levels of an organization.
App development	C5	Development of products to decrease human intervention and the possibility to control remotely and the developing interactive programs for total quality management.
Scalability	C6	The ability to support data, devices, analyze, people and information
Management system	C7	To stay competitive, companies have to make some technological changes to their management processes, practices, and systems. An appropriate quality management system according to industry-based processes and technologies enables product development, increases customer satisfaction, and reduces the cost of business failure.
Compliance	C8	Compliance activities include compliance with legal, industrial, customer, and domestic requirements
Culture	C9	Organizational culture plays an important role in implementing Industry 4.0 to support the company's novel strategies and goals.
Leadership	C10	Quality sector leaders, by supporting new goals, policies and approaches, play an important role in preparing companies to keep pace with industry developments.
Competence	C11	The new technologies usage, scale customization, process digitization, collaborative data volume requires new competencies, knowledge, skills and attitudes in the field of quality.

Then, in the next step, to determine the importance and priority of the criteria, the Bayesian Best-Worst method has been used. For this purpose, first the best criterion is selected and other criteria are compared with it. In the next step, the worst criterion was selected and other criteria were compared with it. It should be noted that the comparisons were made based on the following spectrum (Mohammadi and Rezaei, 2020):

Verbal expressions	Equal importance	Weak importance	moderate importance	Moderate plus	Strong importance	Strong plus importance	very strong or demonstrated importance	very, very strong importance	extreme importance
Value	1	2	3	4	5	6	7	8	9

Based on the comparisons, the best vector (BO), which indicates the priority of the best criterion (B) over the criterion j, and the worst vector (WO), which indicates the priority of the criterion (j) over the worst criterion (W), are shown in Table 4:

Table 4- Expert opinions in various industries

Industry	**Expert**	**BO**	**WO**
Energy	D1	[6,5,4,7,8,7,3,6,5,1,8]	[6,5,3,4,7,3,5,1,6,7,8]
	D2	[5,4,5,5,3,7,3,8,8,3,1]	[5,5,6,3,5,1,8,2,7,6,7]
	D3	[5,3,6,6,4,6,4,7,9,2,1]	[6,3,4,5,6,1,9,3,6,7,8]
	D4	[6,8,5,7,5,5,1,9,4,3,4]	[5,5,4,7,3,6,8,1,4,8,6]
	D5	[8,7,9,3,6,9,2,8,4,1,5]	[4,5,1,7,6,2,8,3,7,9,6]
Shipbuilding	D6	[3,4,6,2,3,8,2,9,7,2,1]	[8,7,6,8,8,2,9,1,2,9,9]
	D7	[6,4,6,2,4,7,1,3,3,2,2]	[2,4,2,5,4,1,7,5,3,6,6]
	D8	[5,2,6,2,4,7,1,6,4,3,3]	[2,6,2,6,5,2,9,1,3,3,8]
	D9	[6,4,5,5,7,8,3,6,7,2,1]	[6,8,1,7,5,4,9,2,3,4,7]
	D10	[3,5,6,3,4,7,4,9,8,3,1]	[7,5,6,7,6,3,9,1,2,8,7]
Food	D11	[5,4,3,4,3,6,2,8,9,2,1]	[6,7,7,6,8,3,8,1,2,7,8]
	D12	[3,3,5,2,5,7,2,8,8,3,1]	[6,7,4,8,7,3,7,1,3,8,6]
	D13	[2,6,7,5,7,2,1,3,6,8,8]	[3,6,1,4,6,3,9,4,6,7,8]
	D14	[8,7,6,7,8,5,1,5,4,6,4]	[5,6,5,8,8,4,9,4,1,7,5]
	D15	[3,5,5,4,5,7,2,8,9,3,1]	[9,8,6,7,8,3,7,1,3,8,7]

After pairwise comparisons, the implementation model and the weight of the criteria were calculated according to Table 5. As Table 4 shows, in the Energy industry, the criteria of leadership, management system and competency with 0.145, 0.140 and 0.118 points are the most important and the criteria of compliance and scalability with 0.051 and 0.058 points, respectively, have the lowest importance. In the shipbuilding industry, the criteria of management system, competence and cooperation are the most important with 0.152, 0.144 and 0.118 points, respectively, and the criteria of scalability, adaptation and culture are the least important with 0.045, 0.047 and 0.054 points, respectively. In the shipbuilding industry, the criteria of management system, competence and leadership with 0.146, 0.115 and 0.107 points are the most important and the criteria of adaptation and culture with 0.054 points are the least important.

Table 5- Weight of Quality 4.0 criteria in different industries

Criteria	Symbol	Food	Shipbuilding	Energy	Total	Priority
Data	C1	0.093	0.080	0.080	0.085	7
Analytics	C2	0.095	0.099	0.080	0.091	5
Connectivity	C3	0.075	0.059	0.070	0.068	8
Collaboration	C4	0.099	0.118	0.083	0.099	4
App development	C5	0.096	0.088	0.088	0.091	6
Scalability	C6	0.065	0.045	0.058	0.056	10
Management system	C7	0.146	0.152	0.140	0.147	1
Compliance	C8	0.054	0.047	0.051	0.051	11
Culture	C9	0.054	0.054	0.087	0.063	9
Leadership	C10	0.107	0.115	0.145	0.123	3
Competence	C11	0.115	0.144	0.118	0.126	2

As Table 5 shows, in general and based on the results of the three studied industries, the criteria of management system, competence and leadership with 0.147, 0.126 and 0.123 points are the most important, respectively. Conformity and scalability criteria are the least important with 0.051 and 0.056 points, respectively. Compares and prioritizing of Quality 4.0 criteria in studied industries are shown in Figures 2 and 3.

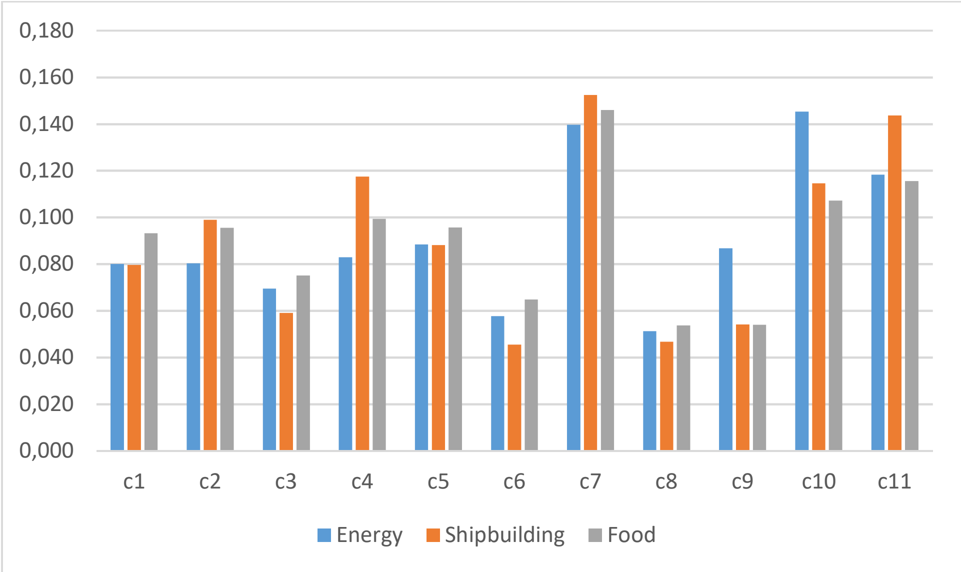

Figure 2- Comparison of criteria weights in the studied industries

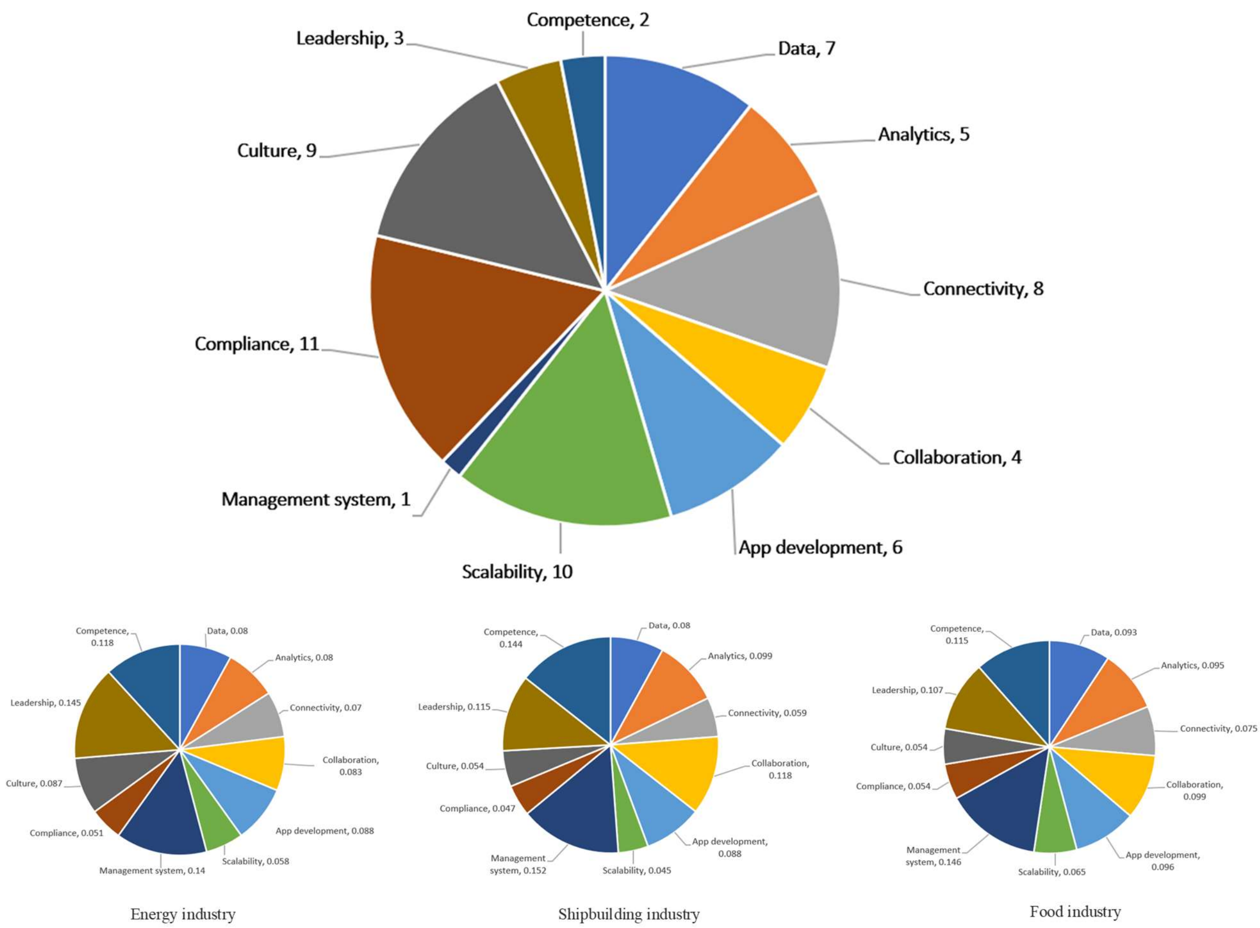

Figure 3- Prioritizing of Quality 4.0 criteria in studied industries

Results and Suggestions

One of the most important criteria that companies must establish in order to adapt to industry 4.0 developments is the ability to store, classify, analyze and identify patterns in big data. This can help the quality of products and services by identifying the needs of customers and identifying their consumption patterns. Due to the huge increase in data volume, traditional management systems does not have adequate capacity for processing. Therefore, it is necessary to invest in this sector to provide analysis tools and techniques for data and information.

In addition to creating the right capacity to collect and store data, organizations must have the capacity to analyze data and processes. Business analysis helps to increase competitiveness and create value for the organization by adopting appropriate customer-centric approaches to quality, making optimal decisions and applying appropriate strategies. The results showed in the digital era and Industry 4.0 communication is very important. Communication and interaction between people, organizations, processes, products, people and devices lead to the creation of large networks of collaboration. In addition, in this era, due to the enhancing products, processes and technology complexity, problem solving requires the participation and cooperation of individuals and organizations at all levels. Especially in terms of TQM, the participation of all employees at all levels and increased collaboration leads to improved productivity. In addition, the development of automated control programs and systems will decrease human interference and enable controlling processes remotely. With the expansion of smart factories, industrial automation and artificial intelligence, organizations will be able to use interactive programs in quality management.

As the results of this study showed, to increase scalability, companies must create the appropriate capacity to respond and process the number of transactions required by users. Ideally, the system should meet the needs of users for any number of transactions. This requires the development of soft skills and competencies such as leadership, organizational culture, employee competence and a strong management system. Top managers and leaders of the organization working in the quality department must pay more attention to the strategic goals of the company and the valuable actions that support the goals. Due to the changes made in the FIR, the leaders of the organization must support the goals by developing technologies, tools, improving processes and analyzing new data.

Organizational culture plays an important role in supporting a company's new strategies and goals and applying Industry 4 approaches. A rich culture in the field of quality promotes production and organizational changes align with the new customers' needs. In this situation, understanding the need for quality to conform to Industry 4, collaborative environment, interactive communication, transparency as well as focus on continuous improvement which is a strategic factor for organizational competitiveness.

In addition, with the industrial revolution and new technologies usage, process digitalization, customization of scale intensity, large volume of data, and a collaborative environment require the development of new competencies. Since the field of quality plays a key role in an intelligent factory, a strategic approach is proposed that periodically evaluates the competence of employees and uses a learning management system to develop their capabilities. The results showed that in Food, Energy and Shipbuilding industries, management system criteria and competencies are very important. Therefore, it is recommended that companies develop management systems and staff training to obtain the required competencies.

References

ALZAHRANI, B., BAHAITHAM, H., ANDEJANY, M. & ELSHENNAWY, A. 2021. How Ready Is Higher Education for Quality 4.0 Transformation according to the LNS Research Framework? *Sustainability,* 13**,** 5169.

ANTONY, J., MCDERMOTT, O. & SONY, M. 2021a. Quality 4.0 conceptualisation and theoretical understanding: a global exploratory qualitative study. *The TQM Journal,* ahead-of-print.

ANTONY, J., SONY, M., FURTERER, S., MCDERMOTT, O. & PEPPER, M. 2021b. Quality 4.0 and its impact on organizational performance: an integrative viewpoint. *The TQM Journal,* ahead-of-print.

ARSOVSKI, S. Social oriented quality: from quality 4.0 towards quailty 5.0. 13th International Quality Conference, 2019. 397-404.

CHIARINI, A. & KUMAR, M. 2021. What is Quality 4.0? An exploratory sequential mixed methods study of Italian manufacturing companies. *International Journal of Production Research***,** 1-21.

DALENOGARE, L. S., BENITEZ, G. B., AYALA, N. F. & FRANK, A. G. 2018. The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics,* 204**,** 383-394.

DIAS, A. M., CARVALHO, A. M. & SAMPAIO, P. 2021. Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality. *International Journal of Quality & Reliability Management,* ahead-of-print.

DOVLEAC, R. Knowledge management systems in Quality 4.0. MATEC Web of Conferences, 2021. EDP Sciences.

FOIDL, H. & FELDERER, M. Research challenges of industry 4.0 for quality management. International conference on enterprise resource planning systems, 2015. Springer, 121-137.

FONSECA, L., AMARAL, A. & OLIVEIRA, J. 2021. Quality 4.0: The EFQM 2020 Model and Industry 4.0 Relationships and Implications. *Sustainability,* 13**,** 3107.

FRANK, A. G., CORTIMIGLIA, M. N., RIBEIRO, J. L. D. & OLIVEIRA, L. S. D. 2016. The effect of innovation activities on innovation outputs in the Brazilian industry: Market-orientation vs. technology-acquisition strategies. *Research Policy,* 45**,** 577-592.

FRANK, A. G., RIBEIRO, J. L. D. & ECHEVESTE, M. E. 2015. Factors influencing knowledge transfer between NPD teams: a taxonomic analysis based on a sociotechnical approach. *R&D Management,* 45**,** 1-22.

GLOGOVAC, M., RUSO, J. & MARICIC, M. 2022. ISO 9004 maturity model for quality in industry 4.0. *Total Quality Management & Business Excellence,* 33**,** 529-547.

GUNASEKARAN, A., SUBRAMANIAN, N. & NGAI, W. T. E. 2019. Quality management in the 21st century enterprises: Research pathway towards Industry 4.0. *International Journal of Production Economics,* 207**,** 125-129.

HEHENBERGER, P. 2011. *Computerunterstützte Fertigung: Eine kompakte Einführung*, Springer-Verlag.

JACOB, D. 2017. Quality 4.0 impact and strategy handbook: getting digitally connected to transform quality management. *LNS research*.

JAMKHANEH, H. B., SHAHIN, A., PARKOUHI, S. V. & SHAHIN, R. 2021. The new concept of quality in the digital era: a human resource empowerment perspective. *The TQM Journal*.

JANSSEN, M., WEERAKKODY, V., ISMAGILOVA, E., SIVARAJAH, U. & IRANI, Z. 2020. A framework for analysing blockchain technology adoption: Integrating institutional, market and technical factors. *International Journal of Information Management,* 50**,** 302-309.

KRUBASIK, S., DIRLEA, V., KIDAMBI, R. & SACHSENEDR, C. 2015. Quality 4.0: preventive, holistic, future-proof. *ATKearney.* [Online]. Available: https://www.atkearney.com/industrial-goods-services/article/?/a/Quality-4-0-preventive-holistic-future-proof.

KÜPPER, D., KNIZEK, C., RYESON, D. & NOECKER, J. 2019. Quality 4.0 takes more than technology, Boston Consulting Group & ASQ American Society for Quality & DG Deutsche Gesellschaft fur Qualita. Available: https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology.aspx.

KWON, O., LEE, N. & SHIN, B. 2014. Data quality management, data usage experience and acquisition intention of big data analytics. *International Journal of Information Management,* 34**,** 387-394.

MOHAMMADI, M. & REZAEI, J. 2020. Bayesian best-worst method: A probabilistic group decision making model. *Omega,* 96**,** 102075.

RADZIWILL, N. 2018. The Quality 4.0 Revolution: Reveal Hidden Insights Now With Data Science and Machine Learning. Quality.

REZAEI, J. 2015. Best-worst multi-criteria decision-making method. *Omega,* 53**,** 49-57.

REZAEI, J. 2016. Best-worst multi-criteria decision-making method: Some properties and a linear model. *Omega,* 64**,** 126-130.

SADER, S., HUSTI, I. & DAROCZI, M. 2021. A review of quality 4.0: definitions, features, technologies, applications, and challenges. *Total Quality Management & Business Excellence***,** 1-19.

SONY, M., ANTONY, J. & DOUGLAS, J. A. 2020. Essential ingredients for the implementation of Quality 4.0: a narrative review of literature and future directions for research. *The TQM Journal*.

SONY, M., ANTONY, J., DOUGLAS, J. A. & MCDERMOTT, O. 2021. Motivations, barriers and readiness factors for Quality 4.0 implementation: an exploratory study. *The TQM Journal,* 33**,** 1502-1515.

SURESHCHANDAR, G. S. 2021. Quality 4.0 – a measurement model using the confirmatory factor analysis (CFA) approach. *International Journal of Quality & Reliability Management,* ahead-of-print.

YADAV, N., SHANKAR, R. & SINGH, S. P. 2021. Critical success factors for lean six sigma in quality 4.0. *International Journal of Quality and Service Sciences,* 13**,** 123-156.

ZONNENSHAIN, A. & KENETT, R. S. 2020. Quality 4.0—the challenging future of quality engineering. *Quality Engineering,* 32**,** 614-626.

An Integration of QFD and Fuzzy-AHP approach in Hospital Services, case study: a Hospital in Iran

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Purpose

This paper shows a development of an integrated model to identify the customer needs and select the best solution to optimize the quality of healthcare systems, namely at hospitals.

Design/methodology/approach

After determining the patient's requirements by data gathering from experts and patients, a questionnaire was prepared to implement the Fuzzy Analytic Hierarchy Process (FAHP) method. Afterward, the requirement's weight has determined by the patients. Finally, the most important technical requirements were achieved applying the 3-phases Quality Function Deployment (QFD) model.

Findings

The results show that by adapting the FAHP on ideas of the patients and hospital's experts to determine the weights of patients' requirements, led to have more flotation in FAHP questionnaires in the hospital services. In this domain, adopting the decision-making tools help more precise ranking of patients' requirements.

Originality/value

Since high-quality urgent services are vital to the protection of human life, it is significant to precisely rank the patient’s requirements by novel methodologies. By the implementation of an integrated model using FAHP and QFD, we were able to show the improvement of the quality of an hospital in Iran. After precisely ranking the patient requirements, "increasing human resource" and "establishing requirements and instructions in initial measures and reducing medication errors", are obtained as the most important technical requirements.

Keywords: QFD, Voice of Customer, House of Quality (HOQ), Hospital Services, FAHP.

Paper type: Case study.

1. INTRODUCTION

The fast-growing and rapidly changing markets in today's competitive environment have made the product/service quality a key determinant for business success. In general, effective capturing of customer requirements (CRs) is a major advantage for product-oriented firms. In this regard, QFD is an efficient customer-oriented design tool that aims to meet customer expectations in a better way and enhance organizational capabilities while maximizing company goals. In 1972 in Japan, QFD emerged as a sufficient systematic tool in Mitsubishi heavy industry to translate CRs throughout the design, planning, and implementation phases of the product (Li et al., 2014). The QFD helps a company to make a trade-off between what the customer wants and what the company affords to produce. The fulfilment of customer needs depends on features of the product/service which can consider as engineering characteristics (ECs). It is important to determine the requirements that bring more satisfaction to the customer than others. Many industries have employed the QFD technique in various areas including transportation and communication, electronics and electrical utilities, software systems, manufacturing services, education and research, aerospace, agriculture, construction, environment protection, packaging, and so on (Chan and Wu, 2002). The relationship matrix in each stage between CRs and ECs is called the house of quality (HOQ) (Wu et al., 2020). The relationship between CRs and ECs reflects the impact of the fulfilment of the ECs on the satisfaction of the CRs. These relationships should be calculated by QFD team members. The relationship between CRs and ECs and the relationship between the ECs themselves are usually determined by linguistic variables. In other words, they are usually interpreted as symbols which should be converted into crisp numbers. The degree of these relationships is usually expressed on a scale system such as 0-1-3-9 or 0-1-3-5, representing linguistic expressions such as "no relationship", "weak/possible relationship", "medium/moderate relationship", and "strong relationship". Proper implementation of the QFD can lead to improvements especially in product and service build strength, quality, cost reduction, product and service development time, and engineering changes (Yang et al., 2012).

To develop the QFD technique for establishing a more precise ranking process, multi-criteria decision-making (MCDM) methods can be employed. Such methods evaluate a set of alternatives taking different criteria into account under a deterministic or uncertain decision environment.

Nowadays, the AHP method is popular in various decision areas. The triangular fuzzy numbers are used to construct a pairwise comparison matrix to evaluate the requirements as criteria in the AHP method (Alinezhad and Seif, 2020). Therefore, many researchers have used the AHP method as an integral part of implementing the QFD method in various issues. Since high-quality urgent services can save human life and healthcare organizations are one of the pivotal domains, it is vital to develop an integrated model to identify the patient's needs and select the best solution to optimize the quality of healthcare systems. Below we discuss the significant application of integrated QFD-MCDM techniques in service systems. Regarding education application, Bayraktaroğlu and Özgen (2008) presented an integrated method using the AHP, Kano model, and planning matrix of HOQ to evaluate the requirements of the library users. The authors considered the central library services of Dokuz Eylul University and evaluated and categorized the student requirements. Raharjo et al. (2011) proposed a systematic methodology to deal with customer needs' dynamics in terms of the relative weights in the QFD approach. First, the authors proposed a short-term forecasting method to model the dynamics of the AHP based importance rating. After that, it estimated the uncertainty degree of CRs. Then, a quantitative approach that considers the decision maker's attitude towards risk to optimize the QFD decision-making analysis is employed. Finally, the proposed method is adopted for improving education quality in a university in Singapore. Wang et al. (2016) presented a new hybrid group decision-making model based on hesitant 2-tuple linguistic term sets and an extended QUALIFLEX (qualitative flexible multiple criteria method) approach to handle the QFD problems under incomplete weight values. For this purpose, at the first stage, they integrated hesitant linguistic term sets into interval 2-tuple linguistic variables to express various uncertainties available in the assessment information of QFD team members. Using grey relational analysis (GRA), they formulated a multi-objective optimization model to determine the relative weights of CRs. Afterward, they extended the qualitative flexible multiple criteria method (QUALIFLEX) approach with an inclusion comparison method to rank the design requirements identified in the QFD. They validated their proposed methodology through the market segment selection data. To reduce the likelihood of poor and awkward body postures, Mistarihi et al. (2020) used a hybrid QFD-FANP method to assessing the modified wheelchair design. Multiple attribute decision making (MADM) is an approach employed to solve problems involving selection among a finite number of alternatives. A hybrid multiphase fuzzy QFD-MADM framework by integrating the QFD, AHP, decision-making trial and evaluation laboratory (DEMATEL), and analytical network process (ANP) along with fuzzy set theory has been developed by Ocampo et al. (2021) for sustainable product design. They applied the method in meat processing industry in Philippines.

Haber et al. (2020) developed an integrated method of the Kano model, QFD, and FAHP to improve medical haemodialysis devices. In this regard, they converted the CRs into receiver state parameters (RSPs) by the Kano model and applied the QFDforPSS which satisfies market expectations rather than traditional QFD by translating the CRs to product-service system (PSS) functionalities. The PSS models present the combination of product and service in a cohesive system to deliver the consumer functionality with taking into consideration of sustainability. Moreover, FAHP was adapted for reducing the vagueness regarding understanding the CRs. Considering the example of a hip replacement surgery aid device for elderly people, Neira-Rodado et al. (2020) proposed an integrated DEMATEL-AHP-QFD framework to translate the CRs to product features and rank the design alternatives. They employed the fuzzy Kano model to obtain how each CR affect the customer satisfaction.

The healthcare industry plays a vital role in ensuring the sustainable development of a country. Since maintaining people's lives and providing prompt, high-quality health care is more important than other service, it is vital to provide a coherent model for identifying patient needs. For this reason, researchers have been paying particular attention to the development of services in hospitals as one of the main pillars of health care. The growing demand for quality care has led to the need for modern modelling of sustainability for the health care system (Zhang et al., 2014). To provide fast and high-quality services by medical organizations, applying different methodologies to achieve comprehensive quality management can be an effective step. In recent years, QFD has been able to play a role in this field (Campos et al., 2013).

This paper aims to develop an integrated FAHP-QFD method for evaluating the weights of CRs are derived from patients using a series of matrixes of QFD. The importance of CRs is prioritized according to the patient’s opinion based on the FAHP questionnaire. Afterward, from QFD matrixes and considering the ranked CRs, the most important ECs obtained to optimize the hospital services. This study brought up a real case study of a public hospital in Iran to implement a model and help managers of the health system to understand patients’ requirements to provide prompt and high-quality services to protect human life. This paper is structured as follows. Section 2 discusses the proposed model of FAHP and QFD methodology. Section 3 discusses the FAHP approach. Section 4 will define the specific QFD steps in this study, and section 5 illustrates an example of a public hospital in Iran to validate the proposed integrated model. Section 6 concludes the paper. The appendix includes the related HOQ matrix in section 7.

2. PROPOSED AN INTEGRATED FAHP AND QFD MODEL IN HOSPITAL SERVICES

According to the discussed literature in the previous section, the integrated method of QFD and FAHP has not been used in the hospital services considering broad CRs. Therefore, this study tries to study the capability of this integrated method in assessing patients' requirements and identifying key processes to cover them in a hospital as a case study. The implementation of this model is depicted in Figure 1, includes the following steps:

Step 1: First, we tried to determine the criteria and requirements of hospital services by using library studies and searching in previous studies. In this regard, various tools applied such as tree diagram, Kano model, fishbone diagram, existing standards such as GOAL \ QPC criteria, experts in this field, and brainstorming.

QFD team members are represented different hospital units. Therefore, it has been tried to choose the most experienced people in medical affairs in 4 working groups through inquiries and review of work experience and resumes. Also, according to factors such as workload, intensity of impact on the performance of the hospital, as well as the number of staff in the four working groups, 2 people from the headquarters, 1 of the hospital educational supervisor team, 1 of the hospital accreditation team and 3 from the hospital emergency department who were selected as a total of QFD team members.

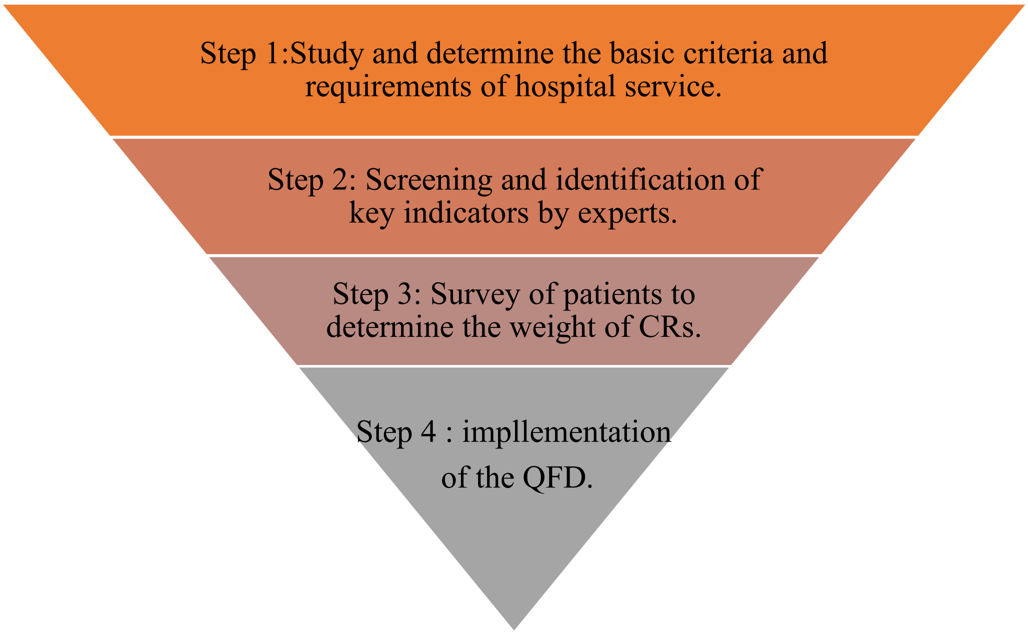

Figure 1– An overview of the proposed integrated FAHP in to QFD model.

Step 2: Prepare a questionnaire to score the main sub-indicators and indicators by experts and screen the most important ones.

Step 3: Form a questionnaire to implement the FAHP method and determine the weight of quality requirements by the customers.

Step 4: This step included the steps for implementing the QFD method, which are:

• Preparing a list of technical requirements by the QFD team members according to the opinion of hospital experts, reviewing related articles, brainstorming.

• Formation of HOQ matrix and measurement of any technical requirements considering the degree of fulfilment of related quality indicators and determination of important and sensitive technical requirements by the QFD team.

• Formation of the second QFD matrix to identify and prioritize executive plans to improve the quality criteria by the QFD team.

• Formation of the third QFD matrix to identify control factors in order to better and more accurately implement executive plans.

3. FUZZY ANALYTIC HIERARCHY PROCESS (FAHP)

The analytic hierarchy process is a ranking method based on pair-wise comparisons used as a powerful decision-making tool. Saaty (1990) has initially been introduced the AHP which is a decision support tool that can be used to solve complex decision problems. It uses a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives. The pair-wise comparisons between criteria instead of their direct weighting is a main key point in this method and lead to increases in the accuracy of the weights. The AHP method can also examine the consistency of judgments, which is a unique feature of this method.

Guan et al. (2009) proposed a hybrid method based on Genetic Algorithm (GA) and AHP method for ranking and selecting multipurpose digital machines. Mangla et al. (2015) used AHP method for risk analysis in green supply chain. The AHP method is a ranking method based on pairwise comparisons in which the criteria and sub-criteria have a hierarchical structure, no matter how many layers are developing. To calculate the importance weights of the sub-criteria, should multiply two matrices ($W_{32} \times W_{21}$). The top of the pyramid is always the objective of the problem. Usually, this structure consists of two levels of criteria and sub-criteria. Since relative weights are based on pair-wise comparisons, the scale of 5 or 9 is normally used to show the degree of importance of criteria (or sub-criteria) compared to each other (Zebardast, 2001). Afterward, a set of questionnaires is designed to collect patients' opinions. The main structure of a questionnaire was developed to implement the FAHP method. Each set of sub-criteria of main criteria is compared in pairs. Finally, after forming a pairwise comparison matrix for each cluster in the hierarchical structure, it has done a set of calculations to obtain the priority vectors and the consistency ratio. Therefore, it is necessary to point out some mathematical equations related to triangular fuzzy numbers.

This monumental work has decades of applications, among them on decision-making under multiple criteria (Abdullah, 2013; Mardani et al., 2015). Let M_1= (l_1, m_1, u_1) and M_2= (l_2, m_2, u_2) two fuzzy triangular numbers, and λ is a crisp number. Then we can denote (Chang, 1996):

$$M_1 + M_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad [1]$$

$$M_1 \times M_2 = (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \quad [2]$$

$$\lambda \times M_1 = (\lambda \times l_1, \lambda \times m_1, \lambda \times u_1) \quad [3]$$

$$M_1^{-1} = \left({}^{1}/_{u_1}, {}^{1}/_{m_1}, {}^{1}/_{l_1} \right) \quad [4]$$

According to the above preparations, the implementation of the FAHP method can summarise in the following steps:

3.1. Calculate the average of decision-makers opinions

After collecting the respondent's views which the detail will discuss in section 5, the average score on each question is calculated and the average weights with the formula below:

$$\overline{r_i} = \frac{1}{m} \times \sum_{i=1}^{m} r_{ij} \quad [5]$$

In this equation, i is the index of questions, j is the index of respondents, m is the number of respondents, and r_{ij} is the answer of the respondent j to the i question, which is itself a triangular fuzzy number of (l_{ij}, m_{ij}, u_{ij}). Also, the expression $\overline{r_i}$ can be represented as the following triangular fuzzy number:

$$\overline{r_i} = (\bar{l}_i, \bar{m}_i, \bar{u}_i) \quad [6]$$

According to Buckley (1985), three components can be calculated as follows:

$$\overline{l_i} = \frac{1}{m} \times \sum_{i=1}^{m} l_{ij} \quad [7]$$

$$\bar{m}_i = \frac{1}{m} \times \sum_{i=1}^{m} u_{ij} \quad [8]$$

$$\overline{u_i} = \frac{1}{m} \times \sum_{i=1}^{m} r_{ij} \quad [9]$$

3.2. Formation of pairwise comparison matrices

The next step is needed to form a matrix of pairwise comparisons for each cluster-criterion after calculating the average opinions of the respondents. The pairwise comparison matrix is a square matrix in which all elements of main diagonals are equal to one. In terms of value, symmetric elements are inverse to each other in this matrix. There is always an injective function between the questionnaire questions and the upper half elements of the pairwise comparison matrix. Therefore, the element of row i and column j (both i and j are criteria indices of the matrix) is related to the question in which the criterion preference i is questioned relative to criterion j.

3.3. Calculate priority vector

There are various methods for calculating the priority vector, including the principal Eigenvalue method, logarithmic least square method, least square method, line sum method, column sum method, arithmetic mean method, and geometric mean method (Saaty and Hu, 1998). One of the most widely used approaches in implementing FAHP is the method proposed by Chang (1996). To calculate the priority vector of each matrix, first the average of the elements of each row is calculated. Then, their normalized values are calculated and introduced as the weight of the corresponding criterion to the related row (Diabagate et al., 2017).

3.4. Inconsistency rate of the answers

To ensure the stability of the respondents' pair comparison, the inconsistency rate of each matrix is calculated. The acceptable numerical consistency rate is less than 0.1. The equations below are mentioned to calculate the inconsistency rate of the answers:

$$IR = II/RI \tag{10}$$

$$II = (\lambda - n)/(n - 1) \tag{11}$$

The II shows the inconsistency index, the IR inconsistency rate, n is the number of items compared in the matrix and, λ is the maximum weight of the pair comparison matrix. Also, RI is a conventional value for matrices with different dimensions, which is called the Random Consistency Index. If the answers are inconsistent for each of the matrices, the following set of actions is recommended:

3.4.1. Calculate the inconsistency rate of the answers for each respondent by performing 3.2 to 3.4.

3.4.2. Descend ordering of data on respondents' inconsistency rates.

3.4.3. Remove the answers related to the respondent with the highest inconsistency rate from the set of responses and then calculate the responses' inconsistency rate using the average of the remaining respondents.

Repeat the three phases above (i.e., eliminating the answers with the highest inconsistency rate from the data set) until the inconsistency rate is less than 0.1.

3.5. Calculate the final fuzzy weight of the sub-criteria

To obtain the final weight of the sub-criteria, it is sufficient to multiply the importance weights of the criteria hierarchically. According to the criteria hierarchy (three-layer structure), by multiplying the relative weight of each sub-criterion by the weight of its parent criterion, the final weight of all sub-criteria will be obtained. Note that after calculating the final weight of the sub-criteria, the sum of all these weights will be equal to one.

3.6. De-fuzzition weight of sub-criteria and determine their final crisp weight

One of the concepts proposed in the Chang method is to calculate the magnitude of a triangular fuzzy number compared to another one. The value of a fuzzy number compared to another one will be obtained in equations 12 and 13. Where $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers. If $m_1 \geq m_2$

Then, can be expressed as follows:

$$V(M_1 \geq M_2) = 1 \; Otherwise \;\; V(M_1 \geq M_2) = \frac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} \tag{12}$$

Also, the magnitude of a triangular fuzzy number compared to k triangular fuzzy numbers has resulted from the following formula:

$$V(M_1 \geq M_2, \dots, M_k) = min\{V(M_1 \geq M_i); i = 2, \dots, k\} \tag{13}$$

4. THE QFD STEPS

Nowadays, organizations use a variety of quality topics to produce their product or service, which leads to meeting the customer requirements and ultimately customer satisfaction. The QFD method is a customer-oriented product development tool to translate effectively customer needs to design and implementation requirements in different aspects of the product or service. The three-matrix structure QFD is recognized as one of the most widely applied models in medical centers, hospitals, and service organizations (Venkateswarlu and Birru, 2012). Therefore, the three-matrix QFD method has been adapted to implement the model, which has the following steps:

4.1. Formation of the HOQ

The HOQ matrix is known as the most common part used in QFD. This house contains elements related to the customer requirements called "WHATs" placed in the rows of the matrix. The technical characteristics are called "HOWs" placed in columns. Nevertheless, the common elements with details and a set of actions that must implement are depicted in Figure 2.

The QFD and the HOQ matrix start with the customer's needs regarding the product. For this purpose, using Benchmarking methods, evaluation of competitors, interviews, focus groups, observing how providing services, staff opinions, reviewing the records of complaints and non-compliance, the customer expectation from desired product or service is determined. Then it needed to rate customers' requirements in terms of importance. There are several manners to weigh these criteria. It is possible to use a range of discrete numbers such as "1 to 5" or "1 to 10". For this purpose, to increase the accuracy of the importance ratings, the FAHP method has been used. The QFD team members must develop a set of technical characteristics to meet these CRs after the identification by the customers. A list of ECs can be extracted by experts, it can expect for an EC to meet more than one CR with different levels of importance. It is important to note that all ECs must be measurable and clearly stated transparently and unambiguously.

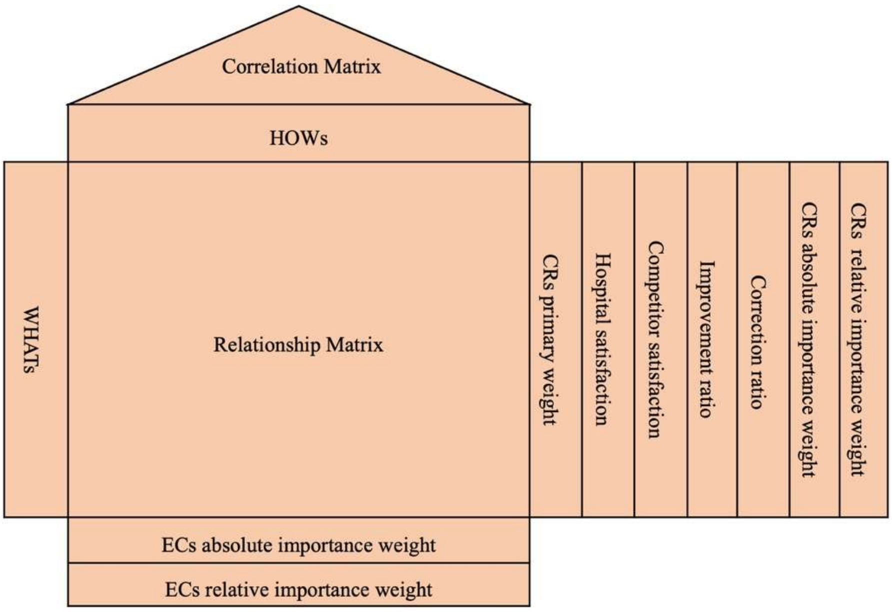

Figure 2 – The main components of the HOQ matrix.

Organizations that want to compete in the market must know what position and rank their product or service from the customer's perspective. According to fulfilment of activities, they want to compare with other competitors; For taking account of this in the HOQ, on the right side of the HOQ matrix, the product or service is evaluated with a similar product or service from competitors. In this step, we designed a questionnaire for data collection from the statistical population of patients in the related hospital and the competitor to evaluate the hospital service performance " (the questionnaire not presented) ". The scoring range of 1 (for the worst condition) to 10 (for the best condition) was used to show the hospital performance in the related criteria. The information collected in this step is in the "Hospital Status" and "Competitor Status" columns in Figure 2, respectively. By obtaining the result of these two columns, the information of the "Improvement ratio" column can also be obtained by dividing the elements of the "Competitor status" column by the "Hospital status" column.

To further emphasize some of the CRs, a coefficient called "Correction ratio" is assigned to them. Therefore, the rate of 1.5 is given to some criteria which bring higher importance for the customer, satisfy them at a higher level, and motivate the customers to use the organization service. Items satisfying the customer but not as much as the first category, get a rate of 1.2. Other criteria that do not need further correction and emphasis are assigned a value of 1.

Afterward, the elements of the three columns consist of " CRs primary weight", "Improvement ratio" and "Correction ratio" are specified. By multiplying the value of these three columns, the " CRs absolute importance weight" column resulted. Finally, by normalizing the absolute weights from the previous step, the" CRs relative importance weight" column be obtained.

The absolute weight of each EC calculates according to the relationship between the corresponding EC and the CR in the following equation:

$$w_i = \sum_{\forall j} c_j \, d_{ij} \qquad [14]$$

Where i represents an EC and j is the index related to criterion (CR), w_i is the absolute weight of the ith EC. The c_j is the index of jth criterion relative importance weight, and d_{ij} represents how the criterion index j is satisfied by the ith criterion. Finally, for the simplicity of comparing the ECs, the relative importance weight of each of them is obtained by normalizing the absolute weights. The HOQ matrix from case study broadly will depicted in section 7.

4.2. Service process deployment

After determining the weights of CRs from the previous stage, it is time to design a set of executive plans to meet these requirements. First, the prior ECs obtained from the HOQ matrix are placed as the rows of the second matrix, and the necessary processes to achieve them are designed. To select the ECs to be transferred to the second matrix due to their large number, those ECs in the fourth quadrant were selected and placed in the rows of the second matrix.

4.3. Evaluate control factors and action plans

The basic requirements of critical processes are determined. The possible operations on these requirements are performed at this stage. Finally, the operations that have been recognized by the organization from customer satisfaction (the expectations expressed in the first stage) will be extracted. Also, we create the control parameters required for execution in this step. Several columns of service operations of the service process deployment matrix are considered rows of the process control planning and action plans matrix (The figure 4 shows this matrix). Afterward, for each of the rows of the matrix with ranges 1 (non-critical), 2 (critical), and 3 (very critical), the four evaluation criteria are determined as follows: 1. The difficulty of the control, 2. Frequency of the problem, 3. The severity of the potential problem, 4. Ability to diagnose the problem.

By Multiplying the weights of the above four factors, the "operation evaluation" indicator, which will be a number between 1 and 81, is calculated for every row in the matrix. The higher value shows the process is more critical and needs action plans. The main objective of this step is to control and monitor the key characteristics of the process and emphasize the amount of control required. Critical processes and operations in the rows have determined. Then, the requirements for controlling are identified in the columns of the process control planning matrix to prevent errors and failures. Figure 3 shows the approach used in the three-matrices QFD.

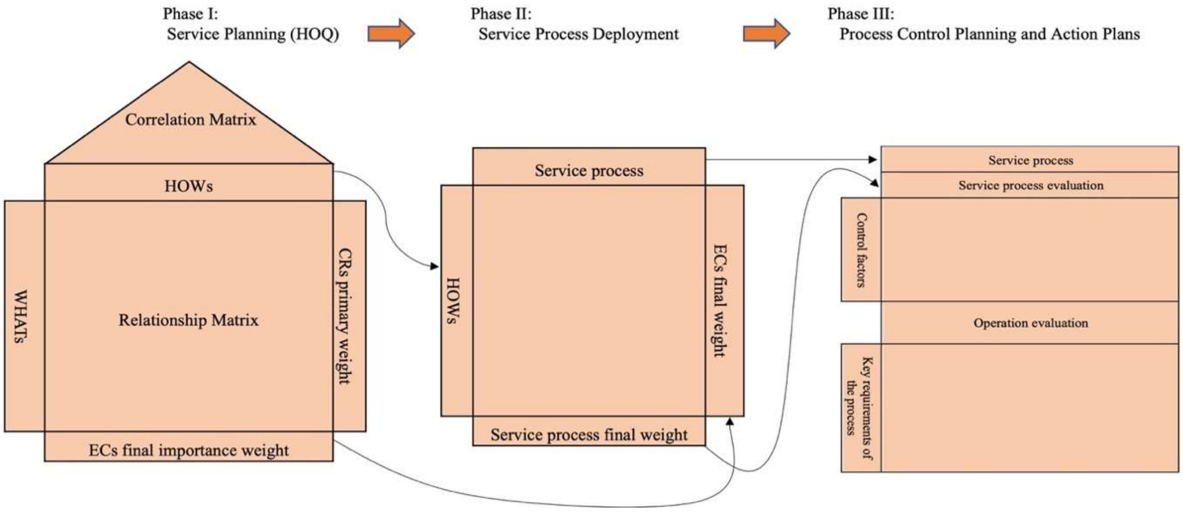

Figure 3 – The three-matrices QFD approach.

5. IMPLEMENTATION OF THE PROPOSED APPROACH

After explaining the general structure of the proposed model, the model is developed in a public hospital in Bojnord, in the North Khorasan state of Iran. This hospital is the first hospital in the state with more than 50 years old after renovation. Recently, it has been upgraded to 225 beds and is the largest hospital in the North Khorasan state which consist of 10 wards and clinical and paraclinical sections. It serves 15000 people per month. In the following sections, steps of the implementation process are presented with the relevant details.

5.*1. Experts survey*

The set of criteria and sub-criteria were designed in a questionnaire format and then provided to the experts. Experts of the organization consist of members of different hospital units such as the management, hospital educational supervising team, quality improvement team, and hospital emergency team. According to Morgan table should have a sample size of 48 for a statistical population of 55 people (Krejcie and Morgan, 1970). After determining the sample size using the random sampling method, we have distributed the questionnaire among the experts. This questionnaire is presented in table 1.

Table 1 – An example of questionnaire options for expert opinion about quality criteria.

Question: How do you assess the importance of the following quality criteria as a measure of patient satisfaction with hospital services?						
Number	Sub-Criterion	Very important	Somewhat Important	Neutral	Somewhat Unimportant	Very unimportant
1	Rapid and on-time response					

The value of Cronbach's alpha for the questionnaire was 0.94, which indicates a high-reliability rate. The center of gravity method has been used to de-fuzzy the triangular Fuzzy numbers. Following equation shows how to calculate the non-fuzzy value of the $M = (l, m, u)$ in the center of gravity method:

$$M = \frac{l+2m+u}{4} \qquad [15]$$

5.2. Patients survey to calculate the sub-criteria weight

An average of 1100 patients registered according to the scope of 6 months from June 2018 to December 2018 and considering the available statistical data in the hospital. Considering Morgan's model, the number of samples is 285 patients (Krejcie and Morgan, 1970). After determining the sample size, we have distributed the questionnaire among the patients. This questionnaire showed in table 2.

For example, to evaluate the importance of the two sub-criteria of " Rapid and on-time response " and " Experienced medical team" in the main criterion of "medical", how to answer the questionnaire depends on the respondent. In one of example:

If from the respondent's point of view, the importance of the sub-criterion of " Rapid and on-time response" is more than the criterion of "Experienced medical team" and the level of importance in the range of 1 (equal preference), 2 (low preference), 3 (medium preference), 4 (High preference), 5 (very high preference), number 5 is completed as follows and shows the very high preference of left sub-criterion than right sub-criterion:

Table 2 – Sample of AHP method questionnaire for the determining the final structure of quality criteria by patients.

Rapid and on-time response	5	4	3	2	1	2	3	4	5	Experienced medical team

Due to the different distribution of patients in various wards, the Stratified sampling method is developed. The hospital wards and distribution of beds showed in table 3.

Table 3 – Distribution of beds in various units of hospital.

	Hospital unit	Number of beds
1	Pediatrics	50
2	Internal diagnosis	38
3	Neurology	18
4	Intensive Care Unit (I.C.U.)	8
5	Infectious disease	8
6	Psychiatric	22
7	Accident and Emergency (A&E)	25
8	Cardiovascular	19

9	Coronary Care Unit (C.C.U.)	11
10	Subspecialty	20

Also, the average inconsistency rate was 0.285, and using the equations of FAHP in section 3, the stages of section 3 implemented to determine the final weights of the criteria are obtained as shown in table 4 according to the questionnaire by experts (after the deadline and reaching the required number of questionnaires) and another questionnaire (patient opinions) distributed it among the statistical population of patients according to the model.

Table 4 – Final weights of sub-criteria in the hospital services using FAHP method.

Weight	Sub-Criteria	Sub-Criteria	Weight
–	Welfare	Medical	–
0.007	Indoor condition (ventilation, light, temperature)	Rapid and on-time response	0.212
0.006	Convenient medical transportation services		
0.003	Entertainment in each room (TV, Books, etc.)	Experienced medical team	0.155
0.004	Communication channels, media, and devices in the room	Hospital equipment	0.097
0.003	Existence of welfare facilities for patients	Ability to communicate with patients effectively	0.019
0.002	Existence of welfare facilities for patient care assistant	Administrative and service	–
		Documentation issuing time	0.044
0.001	Hospital Signage Boards	Hospital environmental hygiene	0.062
0.001	A healthy-eating menu	Timely supply of clean linen and bedsheets	0.026
0.008	sufficient quiet and silence rooms		
–	Psychological support	Personal hygiene, health, and professional appearance	0.015
0.183	Respect for patients by the staffs	Ease of hospital discharge	0.005
0.025	Respecting the Religious and Cultural needs of patients		
0.112	The response rate to patient questions (by doctors and nurses)		

5.3. Identification of engineering characteristics and implementation of QFD

After considering the CRs, to fulfill these demands the ECs are determined by the QFD team. These ECs are located at the top wall of the HOQ and form the columns of the house. In this regard, it has been tried that each EC has a strong relationship with at least one CR.

- **Relationship matrix:** by summing the weight of the sub-criteria and, the evaluation of another hospital in North Khorasan state in Bojnord as a competitor. The relationship matrix (HOQ) is presented in section 7.

- **Process control planning and action plans matrix:** After determining the critical processes and operations in the rows, the requirements for controlling them are determined in the process control planning and action plan matrix columns to prevent errors and failures. Figure 4 shows the process control planning.

		Purchasing advanced cleaning devices	Strengthening the capacity of Human Resources	Recruitment of medical staff	Healthcare assistant training	Arrange psychological courses for staff (specifically for nurses) regarding how to treat patients	Healthcare assistant hiring	Arrange specialized courses in up-to-date treatment methods	Developing instructions and obligations for primary care and reducing medication errors
		9.7	**16.4**	**23**	**7.2**	**11.3**	**10.9**	**8.2**	**13.8**
Control factors	*Difficulty of the control*	*1*	*3*	*3*	*2*	*2*	*1*	*2*	*2*
	Frequency	*2*	*2*	*1*	*1*	*1*	*2*	*1*	*2*
	Severity	*2*	*2*	*3*	*1*	*1*	*1*	*2*	*3*
	Ability to diagnose	*1*	*3*	*2*	*2*	*2*	*2*	*2*	*2*
	Multiplication	*4*	*36*	*18*	*4*	*4*	*4*	*8*	*24*
Key requirements of the process	Various proficiency interviews before hiring			✱			✱		
	Background check for employment			✱			✱		
	Direct supervision over the educational workshops		✱		✱	✱		✱	
	Determining indicators to measure service quality		✱						✱
	Analysis of existing processes		✱	✱	✱				
	Set up a maintenance department	✱							
	Inspection of purchased equipment	✱							
	Develop and implement the necessary measures to prevent failure								✱

Figure 4 – Process control planning and action plans matrix.

6. CONCLUSION

There are always problems when implementing a QFD that team members may encounter at first during the project. These problems are exacerbated when the QFD team seeks to improve service quality. Lack of service quality measurement systems, and lack of measuring tools are among the critical problems in service organizations. Therefore, the QFD team should try to find how to measure service quality and design new methods and tools to measure criteria. In some service organizations, the service delivery process does not have a clear process, in such organizations, analysing the service outputs of the organization is difficult and time consuming.

One of the limitations in collecting information was the inability of some patients to answer questions and the absence of their care assistants then had to be asked each question orally. In some cases, due to the medical care provided to the patient, the interview was forced to be interrupted, which caused a long process of data collection. Some patients did not fully understand the questions and had difficulty receiving the requirements of the questionnaire, and sometimes they were misunderstood. Other problems include congestion and stress on patients and their companions in some wards such as the emergency ward. The implementation of the QFD method led to obtain the voice of customers and their hidden demands that were not identified previously. For example, the item "Respect for patients by the staff", which does not seem to affect the medical criteria has a strong relationship with patients 'satisfaction with the hospital. Also, the item "Hospital environmental hygiene" is not the main factor considered in medical criteria and is one of the most important CRs. According to the HOQ, the most priority CRs concluded the following, respectively: Rapid and on-time response, Respect for patients by the staff, Experienced medical team, and Response rate to patient questions (by doctors and nurses), Hospital Equipment, Hospital environmental hygiene.

In this study, by the integration of QFD and FAHP, CRs were identified and prioritized. Afterwards, a set of action plans to improve the quality of hospital services defined. This method has two advantages. First, pairwise comparison, and second, applying the fuzzy theory. After implementing the integrated model, two ECs "Strengthening the capacity of human resources" and "Developing instructions and obligations for primary care and reducing medication errors" as the most significant technical control requirements in a case study in a public hospital in North Khorasan state in Iran have obtained. Finally, the importance of "Determining indicators to measure service quality", "Direct supervision over the educational workshops", "Analysis of existing processes" and "Developing and enforcing the necessary measures to prevent failure" were recognized as the most important for these key requirements of the process. Future studies can focus more on the following:

- Fuzzy variables can be used by the QFD team in matrices due to improve the accuracy instead of the use of discrete symbols of weights.
- In this study, to weigh the criteria and sub-criteria, the ANP method can be used instead of AHP. Unlike AHP, it considers the advantage of the ANP method over AHP in creating correlation and interaction.
- Due to the use of signs on the roof in the HOQ, which has only a control and warning aspect to control the ECs, these elements can be upgraded to a score that achieves quality requirements and mathematical correlation between ECs.

7. APPENDICES

As mentioned in sub-section 4.1, the relationship between CRs and ECs determines the relationship between quality criteria and technical characteristics in the HOQ matrix. Each strong link has a score of 9, the medium link has a score of 3 and, a weak link has a score of 1. For example, the "Electronic medical record system" is strongly related to the "Documentation issuing time", since if the patient has already been referred to this hospital and has a record, documentation issuing will be easier and faster. Otherwise, the normal procedure for issuing the documents is ongoing. Figure 5 shows the HOQ of the public hospital in Bojnord.

	CRs \ ECs	Average wait time to see the doctor <10 min	Preliminary help pending arrival of doctor	Patience of the staff	Number of nursing personnel	Number of medical staff	Laboratory and radiographic equipment	Advanced Call button beside the patient's bed	Patient discharge rules	Patient admission procedure	Average time of admission process	Cleaning plan	arranging commute in hospital	Number of healthcare assistants	Guidance on uniforms	Elevators and ramps	Arrange psychological courses for nurses	Transport stretcher trolley	Observance of the room's silence	Minimize the light bulb burnt out	Ventilation system	Adequate refrigerator and wardrobe in each room	Electronic medical record system	Providing games and entertainment	Religious and cultural competence procedure	Specialized employee training	Use of cellular telephones in each room	Restroom in each room	Average number of patients in each room	Privacy of the patient	Patient care assistant room	Companion Bed	Existence of signboards	Parking marks and traffic regulation signage	Proper performance of the facility unit	Patient diet adaptation and alternative feeding	Importance	Hospital evaluation	Competitor evaluation	Improvement ratio	Correction ratio	Absolute weight	Relative weight
Medical	Rapid and on-time response	●	●	△	●	●	○	○		○	○	△		○		○		△					○			●											0.212	8	7	0.88	1.5	0.28	0.207
Medical	Experienced medical team		○	○	○	●																				○											0.155	8	8	1.00	1.5	0.23	0.173
Medical	Hospital equipment						●																			○											0.097	9	9	1.00	1.5	0.15	0.109
Medical	Ability to communicate with patients effectively		○		●	○		●						△			●									●							△				0.019	5	6	1.20	1.2	0.03	0.021
Administrative and service	Documentation issuing time	○	○							●	●												●														0.045	8	8	1.00	1.2	0.05	0.040
Administrative and service	Hospital environmental hygiene											●		●														○	△								0.062	7	8	1.14	1.5	0.11	0.080
Administrative and service	Timely supply of clean linen and bedsheets											●		●															○								0.027	9	9	1.00	1.2	0.03	0.024
Administrative and service	Personal hygiene, health, and professional appearance											●			●																						0.015	7	6	0.86	1	0.01	0.010
Administrative and service	Ease of hospital discharge					●			●														△														0.006	10	8	0.80	1.5	0.01	0.005
Welfare	sufficient quiet and silence rooms			○									○						●		○						△		●								0.008	7	6	0.86	1.2	0.01	0.006
Welfare	Indoor condition (ventilation, light, temperature)																			●	●							△	○						●		0.007	7	6	0.86	1.5	0.01	0.007
Welfare	Convenient medical transportation services															○		●																			0.006	7	7	1.00	1.2	0.01	0.006
Welfare	Entertainment in each room (TV, Books, etc.)																							●													0.004	5	5	1.00	1	0.00	0.003
Welfare	Communication channels, media, and devices in rooms																		△								●										0.005	4	4	1.00	1	0.01	0.004
Welfare	Existence of welfare facilities for patients																					●		○				○		○			○				0.004	6	8	1.33	1	0.01	0.004
Welfare	Existence of welfare facilities for patient care assistants							○																△							●	●	○	●			0.003	6	8	1.33	1	0.00	0.003
Welfare	Hospital Signage Boards																																●	○			0.002	4	4	1.00	1.2	0.00	0.001
Welfare	A healthy-eating menu																																			●	0.001	8	9	1.13	1.2	0.00	0.001
Psychological	Respect for patients by the staffs			●								●					●																				0.184	6	5	0.83	1.5	0.23	0.171
Psychological	Respecting the Religious and Cultural needs of patients																								●												0.025	6	7	1.17	1.2	0.04	0.027
Psychological	The response rate to patient questions (by doctors and nurses)			●										●			●																				0.113	8	8	1.00	1.2	0.14	0.100
																																						Total				1.34	1
	Absolute weight	1.983	2.565	3.183	2.571	3.528	1.602	0.819	0.045	0.981	0.981	2.691	0.018	2.473	0.09	0.639	2.628	0.054	0.058	0.063	0.081	0.086	0.986	0.042	0.243	2.898	0.042	0.259	0.227	0.012	0.027	0.027	0.051	0.03	0.063	0.009	32.055						
	Relative weight	0.062	0.080	0.099	0.080	0.110	0.050	0.026	0.001	0.031	0.031	0.084	0.001	0.077	0.003	0.020	0.082	0.002	0.002	0.002	0.003	0.003	0.031	0.001	0.008	0.090	0.001	0.008	0.007	0.000	0.001	0.001	0.002	0.001	0.002	0.000	1						

Figure 5 – The HOQ matrix of the hospital.
△Weak (1) ○Medium (3) ● Strong (9)

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REFERENCES

Abdullah, L., 2013. Fuzzy multi criteria decision making and its applications: a brief review of category. Procedia-Social and Behavioral Sciences, 97, pp.131-136.

Alinezhad, A. and Seif, A., 2020. Application of Fuzzy Analytical Hierarchy Process and Quality Function Deployment Techniques for Supplier's Assessment. Journal of Optimization in Industrial Engineering, 13(2), pp.279-289.

Bayraktaroğlu, G. and Özgen, Ö., 2008. Integrating the Kano model, AHP and planning matrix: QFD application in library services. Library Management.

Buckley, J.J., 1985. Fuzzy hierarchical analysis. Fuzzy sets and systems, 17(3), pp.233-247.

Campos, J.L.G., Veiga, D.F., Rocha, L.R.M., Novo, N.F., Veiga-Filho, J. and Ferreira, L.M., 2013. Quality function deployment in a public plastic surgery service in Brazil. European Journal of Plastic Surgery, 36(8), pp.511-518.

Chan, L.K. and Wu, M.L., 2002. Quality function deployment: A literature review. European journal of operational research, 143(3), pp.463-497.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. European journal of operational research, 95(3), 649-655.

Diabagate, A., Azmani, A. and El Harzli, M., 2017. Selection of the best proposal using FAHP: case of procurement of it master plan's realization. International Journal of Electrical and Computer Engineering, 7(1), p.353.

Guan, X., Wang, Y. and Tao, L., 2009. Machining scheme selection of digital manufacturing based on genetic algorithm and AHP. Journal of intelligent manufacturing, 20(6), pp.661-669.

Haber, N., Fargnoli, M. and Sakao, T., 2020. Integrating QFD for product-service systems with the Kano model and fuzzy AHP. Total Quality Management & Business Excellence, 31(9-10), pp.929-954.

Krejcie, R.V. and Morgan, D.W., 1970. Determining sample size for research activities. Educational and psychological measurement, 30(3), pp.607-610.

Li, M., Jin, L. and Wang, J., 2014. A new MCDM method combining QFD with TOPSIS for knowledge management system selection from the user's perspective in intuitionistic fuzzy environment. Applied soft computing, 21, pp.28-37.

Mangla, S.K., Kumar, P. and Barua, M.K., 2015. Risk analysis in green supply chain using fuzzy AHP approach: A case study. Resources, Conservation and Recycling, 104, pp.375-390.

Mardani, A., Jusoh, A. and Zavadskas, E.K., 2015. Fuzzy multiple criteria decision-making techniques and applications–Two decades review from 1994 to 2014. Expert systems with Applications, 42(8), pp.4126-4148.

Mistarihi, M.Z., Okour, R.A. and Mumani, A.A., 2020. An integration of a QFD model with Fuzzy-ANP approach for determining the importance weights for engineering characteristics of the proposed wheelchair design. Applied soft computing, 90, p.106136.

Neira-Rodado, D., Ortiz-Barrios, M., la Hoz-Escorcia, D., Paggetti, C., Noffrini, L. and Fratea, N., 2020. Smart product design process through the implementation of a fuzzy Kano-AHP-DEMATEL-QFD approach. Applied sciences, 10(5), p.1792.

Ocampo, L., Jumao-as, A.M., Labrador, J.J. and Rama, A.M., 2021. Transforming the means-end chain model of the QFD into interconnected hierarchical network structures for sustainable product design. International Journal of Sustainable Engineering, 14(4), pp.552-573.

Raharjo, H., Xie, M. and Brombacher, A.C., 2011. A systematic methodology to deal with the dynamics of customer needs in Quality Function Deployment. Expert Systems with Applications, 38(4), pp.3653-3662.

Saaty, T.L. and Hu, G., 1998. Ranking by eigenvector versus other methods in the analytic hierarchy process. Applied Mathematics Letters, 11(4), pp.121-125.

Saaty, T.L., 1990. An exposition of the AHP in reply to the paper "remarks on the analytic hierarchy process". Management science, 36(3), pp.259-268.

Venkateswarlu, C. and Birru, A.K., 2012. Integrated quality function deployment as a tool for quality achievement in healthcare. International Journal of Applied Industrial Engineering (IJAIE), 1(2), pp.80-92.

Wang, Z.L., You, J.X. and Liu, H.C., 2016. Uncertain quality function deployment using a hybrid group decision making model. Symmetry, 8(11), p.119.

Wu, S.M., You, X.Y., Liu, H.C. and Wang, L.E., 2020. Improving quality function deployment analysis with the cloud MULTIMOORA method. International Transactions in Operational Research, 27(3), pp.1600-1621.

Yang, C.L., Huang, R.H. and Ke, W.C., 2012. Applying QFD to build green manufacturing system. Production Planning & Control, 23(2-3), pp.145-159.

Zebardast, E., 2001. Application of analytic hierarchy process (AHP) in urban and.

Zhang, L.L., Aldanondo, M. and Kumar, A., 2014, December. Healthcare platforming for healthcare service development in hospitals. In 2014 IEEE International Conference on Industrial Engineering and Engineering Management (pp. 321-324). IEEE.

Properly Using Technology to Ensure Quality (A Reflection Concepts and Implementation)

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ABSTRACT

Purpose - Based on a study that was done worldwide by Forbes Insights in Association with ASQE (American Society for Quality Excellence), ASQ (American Society for Quality) and EOQ (European Organisation for Quality), entitled “JOURNEY TO EXCELLENCE: Navigating the Road To Quality In Today’s Technology-Driven Companies” – 2020, were it was examined how quality initiatives are progressing in the digital era, according to the results of the study, the main challenge identified, from the perspective of the quality professionals (operational level) was “Properly using technology to ensure quality”.

This seems to be aligned with the roles that the Quality professionals have in the organizations, and simultaneously link quality to technology, that is fully related with the concept that we know as Quality 4.0, or the role of quality in the digital progress (digital transformation).

Following the main challenges identified in the study, from the point of view of those responsible for quality (Operational challenges) - ”Properly using technology to ensure quality”, the purpose of this article is based on a bibliography research to understand the concepts and techniques related to the "Use of technology to ensure Quality" and its importance, together with a structured roadmap approach to implement them in organizations.

Design/methodology/approach - In the definition of the topic and the audience, we have come across a series of recent papers and conferences related with quality 4.0, that call for a critical summary, and we identified an interesting and well-defined issue on a study that was done worldwide by Forbes Insights in Association with ASQE (American Society for Quality Excellence), ASQ (American Society for Quality) and EOQ (European Organisation for Quality), entitled “JOURNEY TO EXCELLENCE: Navigating the Road To Quality In Today’s Technology-Driven Companies” –

2020, were the main challenge identified, from the perspective of the quality professionals (operational level) was “Properly using technology to ensure quality”. This seemed to us a very well-defined topic and that would get quality professional readers interested in the review.

After having chosen our topic and audience, we start by checking the literature using the ScienceDirect and Google Scholar databases, by searching for articles and books published in the last 10 years using the following keywords (quality 4.0, quality and industry 4.0, vision for quality 4.0, quality management and digital transformation, skills that quality should develop, quality tools in the context of industry 4.0, quality professionals in I 4.0), and downloading and keep track of the relevant papers, using Mendeley paper management system.

After having taken notes while reading the literature, we had a rough idea of the amount of material available for the review. So, in order to keep the review focused, we decided it would be a good time, to do a mini review, where the aim was to ensure that the contents made sense and to bridge the gap between fields.

To organize the flow of the main body of the review so that the reader will be drawn into and guided through it, we draw a conceptual scheme of the review, with mind-mapping techniques. These diagrams helped us to recognize a logical way to order and link the various sections of the review and to structure the text too.

This methodology/approach allowed us to make a review of articles and other sources relevant to topic of this article and provided a summary description, a critical evaluation and reflection of these works to gain understanding, build and present knowledge on concepts and implementation roadmaps to the topic of study.

Findings - We have built an understanding and present knowledge on concepts and implementation roadmaps to the challenge and topic of study.

Practical implications - Understand the concepts and techniques related to the "Use of technology to ensure Quality" and its importance, together with a structured roadmap approach to implement them in organizations.

Originality/value - We have presented an understanding and knowledge on concepts and implementation roadmaps to the main operational challenge that quality professionals are facing today.

Keywords: Digital Transformation, Quality 4.0, Quality professionals challenges in the digital era, use of technology to ensure quality.

Paper type: Empirical Research paper

INTRODUTION

The objective of the article is to reflect how quality initiatives are progressing in the digital era, namely their relationship with digital transformation and Quality 4.0, in particular regarding the main challenge identified from the perspective of quality professionals, at the operational level, in a recent study, which refers to "Properly using technology to ensure quality", and, based on bibliographic research, understand the concepts and techniques related to the "Use of technology to ensure Quality" and its importance, together with a structured roadmap approach to implement them in organizations.

The relevance of this article is justified by the fact that the study done worldwide by Forbes Insights in association with ASQE (American Society for Quality Excellence), ASQ (American Society for Quality) and EOQ (European Organisation for Quality), entitled "JOURNEY TO EXCELLENCE: Navigating the Road To Quality In Today's Technology-Driven Companies" - 2020, identified the theme of the article as the main quality challenge that quality professionals will face.

Based on the bibliographical research and reflection done during the article, we intend to contribute to the body of knowledge in this area, clarifying concepts, techniques, and the importance of the use of technology to ensure quality, as well as, presenting some structured roadmap approaches to implement them in organizations.

This article is structured as follows. It begins by reflecting on the concepts of quality and Industry 4.0, as well as the vision for the called Quality 4.0 and how these aspects may contribute to ensure quality. Having understood the relationship and the importance of these concepts, it is important to understand the role of quality management in the digital transformation and of quality professionals in Industry 4.0 and which competences they should develop. We will proceed to exploring which quality management tools and techniques are appropriate in the context of the fourth industrial revolution, particularly in smart manufacturing, and the top use cases (the top applications of quality 4.0 at each stage of the value chain) selected by each stage of the value chain.

Finally, we present 3 structured roadmap approaches to implement these concepts in organizations.

RESEARCH METODOLOGHY

A literature review methodology has supported this research.

We have made a review of articles and other sources relevant to topic of this article and we provided a summary description, a critical evaluation and reflection of these works to gain understanding, build and present knowledge on concepts and implementation roadmaps to the topic of study.

QUALITY AND INDUSTRY 4.0

Throughout its history, quality has suffered changes and gone through several phases, largely to adapt to the evolution of manufacturing processes and business needs.

These changes can be described in 4 phases:

1. Quality Inspection: inspection of the products/services produced, where statistical control allows us to identify variations.

2. Quality as Design: conceiving quality at the level of processes in the logic of error prevention.

3. Quality as Empowerment: ensuring that quality is everyone's responsibility and that each individual contributes to continuous improvement (E.g., TQM, Six Sigma).

4. Quality as Discovery: viewing and analyzing data in real time and quickly discovering causes and taking actions to improve products/services and the organization.

(Golan, 2019)

Today, in the context of technological advances, digitalization processes and Industry 4.0, we are in the fourth phase, called quality 4.0, which focuses precisely on how quality methodologies are applied in the digital age and allow organizational excellence to be achieved. Therefore, the more involved quality professionals are in these processes, better opportunities they have to lead these changes. (Qualitymag, 2018)

The technology gap that currently exists between Quality 4.0 and Industry 4.0 can have a negative impact on the industry, but a quality management system that has the ability to provide reliable information throughout the supply chain to all involved and that enables real-time decisions to be made to improve quality and manufacturing processes, can in a practical way reduce the gap between Quality 4.0 and Industry 4.0. (Golan, 2019).

In this context, quality management must adapt, using data-based evidence for real-time decision making, but not forgetting quality technologies, processes, and people that impact digitalization. Many companies are looking for business models that fit this perspective.

Defined digital transformation as an enterprise that incorporates digital and physical elements to transform business models and sets new directions for the industry. This broad concept describes the transformation of processes, digitizing assets, and changing the way organizations think and work; the creation of new type of leadership and business models; and the use of technologies to enhance the experiences of customers and employees. (Lee et al., 2019)

Quality 4.0 comes from Industry 4.0 and is linked to operational excellence in the current context of digital transformation.

The disruptive changes brought by the fourth industrial revolution raise the need to think about quality from a perspective that allows it to adapt, to improve the quality of products and services, and the performance of the organization. (Radziwill, 2018)

VISION FOR QUALITY 4.0

In the context of Industry 4.0, the quality and performance improvement objectives remain similar (conformity, reduction of variation, waste, rework, prevention of defects and human errors, productivity improvement, efficiency, effectiveness, usability, customer experience, innovation, and value-added activities).

The two biggest changes observed, are:

1. The amount of data increasing,

2. Quality goals can be achieved more quickly and completely because emerging technologies are becoming more powerful and accessible.

This allows us to achieve lower costs and increase profits, because prevention and self-correcting activities based on real time data require little intervention or can be done automatically (E.g., audits and management reviews performed by software), with practically no failures. However, some prevention activities continued to be necessary (e.g., calibrations and maintenance) but with a significant reduction in costs.

About the new perspectives anticipated in quality that can be covered by Quality 4.0, comprehend:

- The focus on efficiency, effectiveness and satisfaction has been replaced by continual learning and adaptation,
- Availability and transparency of information within and between organizations and how it is shared,
- Monitor, assess, and respond in real time throughout the supply chain to any situation
- An expansion of the customer experience and the customer's participation in, among other aspects, in design and development, consumption and production, etc.

(Radziwill, 2018)

ENSURE BETTER QUALITY

How using technologies can ensure better quality, help your organization, and bring value?

An initiative linked to Quality 4.0 enhances the company's capacity, namely, making systems connected, intelligent, and automated can:

- Reveal – opportunities for continuous improvement, new business models,
- Anticipate – changes, ability to adapt to new circumstances,
- Improve - transparency, traceability, auditability, speed and quality of decision making,
- Help – people and systems to learn how to learn, cultivate awareness,

(Radziwill, 2020)

Digitalization of the quality management system, which embraces people, processes, and technology, does not replace traditional quality tools and methodologies, and can ensure better quality, through:

- Automated verification of processes and products,
- Taking initiatives proactively by collecting, monitoring and analysing data using analytics to detect deviations and implement effective actions to avoid divergence from targets.
- Reduction of manual errors, variability, inspection time, measurement system variation, repeatability and reproduction analysis
- Faster and effective resolution of problems,
- Improving agility, lead times,

That lead to, decreasing processing time, produce better products at lower cost, reduce costs of poor quality, improve responses to changes in demand, and competitiveness.

(Tomic, 2020)

QUALITY MANAGEMENT AND DIGITAL TRANSFORMATION

The focus of Quality Management must be on the main issues that the organization and the professionals in the field encounter today.

Today digital transformation is often seen as one of the highest risk organizational changes, and quality management has relevant experience in successfully managing change. For this reason it is important to understand how quality management can contribute to the company's digital transformation and to organizational performance. A great potential can be linked to the fact that it is very involved at the strategic and change management level.

Quality management has for these reasons a high potential to support the organization's digitalization activities. (Ponsignon et al., 2019)

QUALITY PROFESSIONALS IN INDUSTRY 4.0

We would start by doing a reflection on, what some changes brought by Industry 4.0 may signify for quality professionals:

Currently the context in which quality professionals move and have been working, has more to do with systems and products, but with the increase in systems integration and complexity brought by connected devices, we may see platforms as the new context, which requires skills in risk management, quality management, user experience design (UX) and in working with the platforms and connected domains to ensure the quality of the customer experience throughout his entire journey.

Beyond standards, models, structures and methods, quality professionals must have as their main area of concern the impact of outcomes and customer experience, to deliver a good story to share and have an impact on the customer experience.

Since quality professionals have process and technology knowledge, they can go a step ahead of quality and process improvement methods and be change agents supporting teams in the transition to Industry 4.0. (Ranganath, 2020)

Regarding Quality Managers' expectations related to the increase and deployment of smart technologies in 2025,

The deployment of complex technologies is influenced by:

1) The branch of industry,

2) Number of pre-manufacturing, manufacturing, post-manufacturing and cross-manufacturing processes,

3) Scope of individual processes,

4) The actual rate of data, digitalization and automation of processes,

5) Actual state of production system integration,

6) Actual state and number of smart technologies,

7) Requirements of concerned parties concerning utilization of smart technologies (especially suppliers and customers).

The technologies that are the most meaningful, are:

- Smart glasses, (in nonconformity management, quality control, change management, dispatching and manipulation);
- Smart gloves, (in quality control, dispatching and manipulation);
- Smart watches, (in nonconformity management);
- RFID technology, (in dispatching);
- Barcodes a QR codes, (in logistic processes, and QR will supplant the Barcodes);
- Drones, (in logistic processes);
- Autonomous vehicles, (in warehousing, dispatching and transportation);
- 3D printing, (in manufacturing and will be expanding in pre-manufacturing processes);
- Simulation by virtual reality, (in product development, continuous improvement and change management);
- Collaborative robots, (in manufacturing).

It is important to emphasize that the choice of the intelligent technologies used depends largely on the type of industry. (Závadská and Závadský, 2020)

Because quality professionals have the competencies related to: Systems thinking, Data-driven decision-making, Leadership for organizational learning, Establishing processes for continuous improvement, Understanding how decisions affect people: lives, relationships, communities, well-being, health and society in general, among which the latter is especially relevant, we think they are well placed to drive a digital transformation. (Radziwill, 2018)

SKILLS THAT QUALITY SHOULD DEVELOP

According to what we have mentioned in the previous points, it becomes evident that the QM function needs to acquire new skills to maintain its value and its relevance in organizations.

There are six competencies that QM must have to justify its participation and contribution in the digitalization initiative of the organization.

Thus, the capability of QM to play an active and meaningful role in the digital transformation, depends on:

- 3 Structural competencies

(Stakeholders focus, tools and methods, global, cross functional vision)

- 3 Contextual competencies

(Digitalized QMS, collaboration with IT, changed QM image)

Both competencies facilitate QM's journey into digital transformation. (Ponsignon et al., 2019)

QUALITY TOOLS AND DIGITAL TECHNOLOGIES IN THE CONTEXT OF INDUSTRY 4.0

We intend to explore which quality management tools and techniques are appropriate in the context of the fourth industrial revolution, particularly in smart manufacturing.

Despite the nearly 400 quality tools and techniques that exist, it has been shown that many quality problems in industry, can be solved by using the following tools and techniques:

Statistical Process Control (SPC), Failure Mode Effect Analysis (FMEA), Design of Experiment (DoE), Model Based Problem Solving (MBPS), 8 Dimension, Fishbone Diagram, and XY Analysis.

(Saifuddin and Syaiful Rizal, 2020)

Another study (Kupper et al., 2019), revealed the importance of quality at each stage of the value chain (% of participants that rate Quality 4.0 in the value chain from End to End), and the top use cases (the top applications of quality 4.0 at each stage of the value chain) selected by each stage of the value chain.

Table I - The importance of Quality at each value chain stage and top use cases

Value Chain Stage	% Of participants that rate Quality 4.0 in the value chain from End to End	Top applications of quality 4.0 at each stage
Manufacturing	74%	• Predictive Quality • Machine vision quality control • Digital standard operating procedures (SOP's)
R&D	74%	• Simulating tests • AI (Artificial Intelligence) • IOT (Internet of Things)
Service & After Sales	64%	• IOT (Internet of Things)
Procurement	59%	• Digital Dashboards
Logistics and Sales	52%	• Big Data Analytics

Cross-Functional	N.A.	• Centralization of Quality Data • An End-to-End Quality Management System • Quality Cost transparency

Source: Adapted from (Kupper et al., 2019)

DIGITAL EXPERIENCE QUALITY

Today the Digital Voice of the Customer and their experience can be done through real-time data-driven analytics, and technology allows us to see everything that can impact Digital Experience Quality.

With the rise of digital transformation and the consequent expansion of digital products and services, digital experience quality takes on a greater role in the success of companies, as claimed by 4 out of 5 C-level executives. However, about 55% of these executives do not know how to identify the aspects that affect quality, and consequently 34% consider it an obstacle, to know where to start developing an improvement strategy, and 34% in identifying the costs inherent to the aspects that need to be improved.

In this context, Business Leaders should consider the next phase of digital transformation: Quality of the Digital Experience, (Ambrose, 2016).

ROADMAPS

In this section we bring together some of the points mentioned in the previous sections to develop Quality Driven Roadmaps for Digital Transformation and to put them into practice in the organization.

The Roadmaps that we will present in this section as examples and their redaction, are not supposed to replace the consultation of the sources mentioned in each one of them, but only to make an overview of the Roadmaps in a way that they can be understood by those who read this article.

1th Example of Roadmap,

Based on (Radziwill, 2020), we have built the following Roadmap, represented in Table II.

Table II - Quality Driven Roadmaps for Digital Transformation (1th example)

Step	Description
Step1	Create an Organizational Profile

Create an Organizational Profile	
Step2 Establish Strategic Orientation and Quality Performance Goals	Help you to identify the best focus. Based on your organizational profile and, strategic advantages Vs organizational capabilities, you should choose in which mechanisms for digital transformation you want to focus. Once you have identified your focus area, you should evaluate the quality and performance goals, to establish why your organization is motivated to pursuit that focus and identify your quality goals associated with transformational mechanisms.
Step3 Establish Value Proposition and Potential Initiatives	Brainstorming A brainstorming grid to convert quality and performance goals to initiatives. Contextualization Presents ideas for how you can realize your digitalization transformation objectives. NOTE: All organizations should have an organizational backbone in place, supported by solid data management, too coordinate people, processes, and technologies. ISO 9001, TQM, Lean Management can all be used for this, because they provide a framework for translating strategic objectives into actions, clear roles, responsibilities, and accountability, and approaches to learning and communications. The digital platforms supports connectedness among people, machines and data. Gap Analysis An accurate assessment of the gap will help you to determine whether pursuing the initiative is feasible, and how much of connectedness, intelligence, automation is appropriate to achieve defined quality and performance goals. Every project or initiative will have its own context, and what is appropriable and desirable in one case may be inappropriate, dangerous, infeasible, or unethical in other.
Step4 Prioritize Initiatives	You should have a list of potential initiatives that match the strategy and quality goals (we identify in step2). Before moving forward, prioritize and evaluate each one in terms of: • Magnitude, The extent of negative or positive impacts in customers, stakeholders, employees, society, environment. • Opportunity, How well the initiative affirms strategic advantages, responds to strategic challenges, captures opportunities, and or addresses intelligent risks. • Deployment, Workforce capability, capacity, and available assets exist (or can be obtained) to advance the initiative.
Step5	The key decisions that need to be made at this step for a digital

Key Decisions for a Digital Transformation Strategy	transformation strategy.
Step6 Determine KPI's	KPI's should be tied to the quality and performance goals we outlined in step2.

2th Example of Roadmap,

Quality Management (QM) involvement in digital transformation is described and illustrated in Figure 1 as having three main components, comprising four phases and nine main activities, as illustrated, and which we will now describe in more detail:

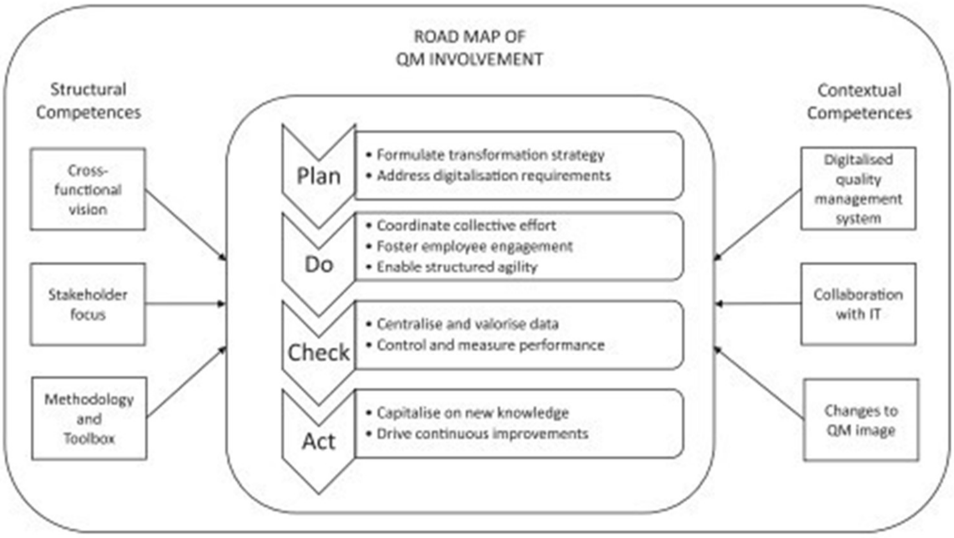

Figure 1 – The contribution of QM to an organization

Source: Adapted from (Ponsignon et al., 2019)

<u>Structural Competencies</u>

These represent the skills and knowledge that constitute the core of the QM position.

- Cross-functional vision

Cross-functional projects are frequently guided by QM and digitization is a cross-functional project (which eliminates barriers, silos and territories). It is clear that QM has a role to play in digital transformation.

- Stakeholder Focus

QM has in many cases QMS (Quality Management System) focused on stakeholder needs and expectations, which makes it easy to see their role in the development, deployment and renewal of digital tools and applications.

- Methodology and Toolbox

QM's expertise in tools and methods, such as risk management or techniques that ensure alignment between requirements and digital functionality, in doing benchmarking to identify best practices and in applying problem-solving techniques, as well as in implementing a methodical approach to managing projects, defining precise objectives, and monitoring them, can together enable a logical and effective approach.

Contextual competences

Refer to the competences that QM must have for the digital transformation.

- Digitalized Quality Management System

Implies the use of digital QM tools and applications, such as, process and performance management, audits, reporting, and aids in developing a digital culture inside and beyond the QM function.

- Collaboration with IT

As we mentioned before, digital transformation is a cross-functional process, where QM can provide a business-oriented framework and IT a technical one.

- Changes in the QM Image

Sometimes the QM Function is still linked to an image perceived as negative (restrictive, rigid, inflexible, and bureaucratic). The contents developed in this article have the purpose of helping to change this perception and image, clarifying the role that QM can play in the digital transformation.

Roadmap of QM involvement

Step 1: plan the digital transformation.

QM's role in this initial phase is to be involved in how this transformation will be driven and ensure that the entire organization considers the requirements of digitization and the needs and expectations of departments, processes, and employees, and together with IT, to suggest, choose, develop, test, and implement innovative tools, methods and techniques.

Some companies create a cross-functional multidisciplinary committee that defines the strategy and ensures its effective implementation.

Step 2: conduct digital transformation.

In this stage the main objectives are to coordinate all those involved, ensure their commitment, and guarantee the necessary agility, where the role of QM is mainly to facilitate workshops and training to explain the benefits of the changes, provide employees with the necessary skills and then support them in the change and use of technologies, reducing the risk of employees creating parallel processes, with their own rules and ways of working.

Step 3: evaluate the digital transformation.

QM's main activities in this phase are to design and implement ways to monitor the impact of digitalization against the criteria initially defined and to check if they are aligned with the strategy, namely through indicators, scorecards, audits. This evidences should be based on data from business processes and functional departments and checked their validity, reliability and relevance. The results of the performance obtained must be communicated to the stakeholders considered relevant.

Step 4: Adjust the digital transformation.

In this last stage QM is responsible for keeping knowledge up to date based on performance and excellence, considering not only the best practices but also the knowledge that already exists internally, fostering internal practices of sharing the knowledge related to digitalization.

(Ponsignon et al., 2019)

3th Example of Roadmap,

Step 1: Define digital transformation and what is look like.

Fill out table III to show how your company defines people, processes, technology, and infrastructure before and after the digital transformation.

Table III – Quality driven roadmap for digital transformation (3th example)

	Current State	Ideal State	What's preventing Ideal State	Gap: People, Pro, Tech,	Bridges

				Infr, Other	
People					
Process					
Technology					
Infrastructure					
Others					

Source: Adapted from (Costich, 2021)

Step 2: Define your problem (or opportunity) statement.

Create a problem or opportunity statement for your organization's digital transformation journey using table III.

Step 3: Determine and define your organization current state

The next step is to establish or describe your organization's current state in relation to the problem or opportunity statement in table III (in terms of people, process, technology, and infrastructure).

Step 4: Define your organizational ideal state

Determine how you want your company's digital transformation to look like.

Always keep in mind that you can't manage a company if you can't see it.

Customers, markets, and competition, financial effect, internal operations, and processes are all critical business factors to consider.

You should also keep in mind that businesses must be flexible and innovative in order to respond to rapidly changing market conditions and customer demands.

Visualize your company's ideal or desired scenario in terms of people, process, technology, and infrastructure using table III.

When faced with adversity, really competitive organizations transform, not merely change.

Change can be gradual and modest. Change begins with the same mental framework and aims gradual or modified improvements rather than a paradigm shift or a major change.

Transformation involves changing one's beliefs so that acts become natural and, as a consequence, the intended result is achieved. It necessitates a paradigm shift and leads to significant improvements.

However, culture isn't the only factor to consider when it comes to digital transformation; the process and technology, as well as how all three elements interact, will truly define a company's transformation journey.

The next step in understanding how to succeed in a digital transformation journey is to discover what's keeping the company from reaching its ideal state.

Step 5: Identifying obstacles to obtain the ideal state template.

Once the current and ideal states have been identified, use table III to determine what is keeping the organization from reaching the ideal state. Consider the organization's people, processes, technology, and infrastructure.

Step 6: Identify Gaps and Bridges

By defining the difference between the existing and ideal states in table III, you must create a successful transformation strategy and tactical plan during this phase.

(Costich, 2021)

CONCLUSIONS

Historically, quality has adapted to the emerging needs and evolutions of business and manufacturing processes and has therefore gone through several phases.

Quality Inspection and Quality as Design were the first two phases that Quality went through on its journey. It is still relatively common to talk about and find several companies in the third phase, which is Quality as Empowerment (ensuring that quality is everyone's responsibility, and that each individual contributes to continuous improvement (E.g., TQM, Six Sigma).

Quality is currently in its fourth phase, called "Quality as Discover" or "Quality 4.0", as a response to the context registered in technological developments, digital transformation, and Industry 4.0. This allows organizational excellence to be achieved through real-time data analysis, which enables us to quickly identify causes and implement decisions that lead to the improvement of products/services and of the organization itself. (Qualitymag, 2018)

Quality management through decisions made in real time, obtained from the reliable information collected all along the supply chain, which it can make available to all the players, and taking into account the quality technologies, processes and people that impact it digitalization, Quality can in a practical way reduce the gap that exists today between Quality 4.0 and Industry 4.0 (Radziwill, 2018).

Despite the developments we have discussed in the previous paragraphs, namely the technological ones, the quality and performance improvement objectives remain the same (conformity, reduction of variation, waste, rework, prevention of defects and human errors, productivity improvement, efficiency, effectiveness, usability, customer experience, innovation, and value-added activities). However, in the context of Industry 4.0, the biggest changes and challenges are:

1. The volume of data is growing massively,

2. As emerging technologies become more potent and available, quality objectives will be reached in a faster and more efficient way. (Radziwill, 2018)

According to (Tomic, 2020), to ensure better quality, decrease processing time, produce better products at lower cost, reduce the costs of poor quality, improve responsiveness to changes in demand, and competitiveness, by addressing the two points mentioned above, we do not need to substitute the traditional quality tools and methodologies, but to embrace people, processes and technology in the digitalization of the quality management system.

One more important thing to consider, to ensure the quality of the customer experience all along his journey and for us to be change agents assisting teams in the transition to Industry 4.0, is to realise that the new context in which quality professionals work today is not so much about systems and products, as it has been in recent years, but more about platforms, and connected domains, which requires skills in risk management, quality management and user experience design (UX). (Ranganath, 2020)

In addition to the skills mentioned above, for QM professionals to play an active and significant role in the digital transformation, they must also have, the following six skills:

- 3 Structural competencies

(Stakeholders focus, tools and methods, global, cross functional vision)

- 3 Contextual competencies

(Digitalized QMS, collaboration with IT, changed QM image)

These two competences make the digital transformation of quality management easier. (Ponsignon et al., 2019)

Following on from what was said before, it also makes sense to examine which tools and techniques of quality management are relevant in the context of the fourth industrial revolution, especially in smart manufacturing.

A recent study (Kupper et al., 2019) showed the evaluation made by the participants, about the relevance of quality 4.0 in each stage of the value chain, as indicated in table I.

At last, we bring together some of the points mentioned in the previous sections to develop Quality Driven Roadmaps for Digital Transformation and to put them into practice in the organization, but it should be noted that the Roadmaps that we will present as examples and their redaction, are not supposed to replace the consultation of the sources mentioned in each one of them.

It should be noted that the topic under study in this article "Properly using technology to ensure quality", was identified in a very recent study (Mckendrick, 2020) where it was examined how quality initiatives are progressing in the digital age, as the main challenge faced today by quality professionals at the operational level.

Because this identified challenge, as well as, the bibliography that supports this theme are both so recent, and having us as the purpose of this article, based on a bibliography research to understand the concepts and techniques related to the "Use of technology to ensure Quality" and its importance, together with a structured roadmap approach to implement them in organizations, several challenges are posed in the scope of the theme of the article that may be developed in future researches.

The theme was developed in a more generic way, essentially for two reasons: during the bibliographical research we noticed that 76% of the articles on this theme that could be relevant for the study were very recent (published between 2019 and 2021) and did not give a direct answer at the operational level, to the question "properly using technology to ensure quality" and how this aspect should be implemented in an organization. For this reason, due to the "youthfulness" of the theme, we thought it would be good to make a brief reflection on the concepts, together with a structured roadmap approach to implement them in organizations.

This study, on the other hand, focused more on how technologies can ensure better quality, with practically no failures, but it does not comprehend or cover in the same proportion, the new perspective of quality 4.0 related to learning and continuous adaptation of products, processes, and business models.

For these reasons, we believe that additional research could be initiated in the future, as more articles are published on the theme, to contribute to clarify concepts, techniques, and the importance of technology to ensure quality, as well as to develop a structured roadmap to implement them in the organization.

REFERENCES

Ambrose, L. (2016), "Business leaders need to prepare for next phase of the digital transformation: digital experience quality", Business Wire, 27 April, pp. 1–3.

Costich, T. (2021), Excelling on a Digital Transformation Journey: A Field Guide to Help You Define Your Success", edited by ASQ, 1st ed., Quality Press, Milwaukee, Wisconsin.

Golan, S. (2019). "New Software Technology: Advances the practicality of quality 4.0", Qualitymag, October, pp. 42-44.

Kupper, D. et al. (2019), "Quality 4.0 Takes More Than Technology", Boston Consulting Group (BCG), August, pp. 1–14.

Lee, S.M. et al. (2019), "The quality management ecosystem for predictive maintenance in the Industry 4.0 era", International Journal of Quality Innovation, Vol. 5 No. 1, pp. 1-11.

Mckendrick, J. (2020), "Insights On Excellence : Navigating the Road to Quality in Today´s Technology-Driven Companies", Forbes Insights, pp. 1–16.

Ponsignon, F. et al. (2019), "The contribution of quality management to an organization's digital transformation: a qualitative study", Total Quality Management and Business Excellence, Vol. 30 No. sup1, pp. S17–S34.

Ranganath, P. (2020), "Do Quality Practitioners Have a Role in Industry 4.0?", www.asq.org, (accessed, 27 May 2021).

Qualitymag (2018), "Industry and Quality 4.0: Bringing them together", October, p.15.

Radziwill, N.M. (2018), "Quality 4.0: Let's Get Digital - The many ways the fourth industrial revolution is reshaping the way we think about quality", Quality Progress, pp. 1–10.

Radziwill, N.M. (2020), Connecting, Intelligent, Automated: The Definitive Guide to Digital Transformation and Quality 4.0, Quality Press, 1st ed., Seiche Sanders, Milwaukee, Wisconsin.

Mena Report (2016), "United States : Microsoft and Jabil collaborate to create quality assurance platform for predictive analytics", 20 April, pp. 1–3.

Saifuddin, I. and Syaiful Rizal, H. (2020), "A study of quality tools and techniques in the context of industrial revolution 4.0 in Malaysia. what's new?", Quality - Access to Success, Vol. 21 No. 174, pp. 88–96.

Tomic, B. (2020), "Inspection in Quality 4.0", Quality, Vol. 59 No. 7, pp. 18–19.

Závadská, Z. and Závadský, J. (2020), "Quality managers and their future technological expectations related to Industry 4.0", Total Quality Management and Business Excellence, Taylor & Francis, Vol. 31 No. 7–8, pp. 717–741.

Further Reading

Radziwill, N.M. (2020), Connecting, Intelligent, Automated: The Definitive Guide to Digital Transformation and Quality 4.0, edited by Quality Press, 1st ed., Milwaukee, Wisconsin.

Costich, T. (2021), Excelling on a Digital Transformation Journey: A Field Guide to Help You Define Your Success", edited by ASQ, 1st ed., Quality Press, Milwaukee, Wisconsin.

Quality Challenges for Management System Certification Bodies – From the Accreditation Point of View

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Abstract

This paper outlines the most common quality challenges Management System Certification Bodies (MSCBs) face during their accreditation process. Accreditation is the independent evaluation of conformity assessment bodies (i.e. Certification Bodies, Inspection Agencies, Testing Laboratories) against recognized standards, to carry out specific activities to ensure their impartiality and competence. Through the application of national and international standards, governments, procurers, and consumers can have confidence in the quality of test results, inspection reports and certifications provided.

This paper provides a study regarding the most common problems in the operation of MSCBs in different countries and regions where the Accreditation Body International Accreditation Service (IAS) provides its accreditation services.

This study has been performed based on data collected on more than 120 MSCBs, from 25 countries worldwide, accredited against the requirements of the international standard ISO/IEC 17021-1:2015 "Conformity assessment — Requirements for bodies providing audit and certification of management systems — Part 1: Requirements" (1).

The Non-Conformities were issued during the accreditation process of various MSCBs offering their certification services in different fields (Agriculture, Food Industry, Textile, Chemicals, Pharmaceuticals, Metals, Construction, Electrical, Aerospace, Engineering Services, etc.). Findings vary from commonly reported quality management system issues to the most critical challenges faced by MSCBs.

The identified non-Conformities were categorized and statistically processed. The trends are identified and analyzed per quality management system or technical category. Under the accreditation process, MSCBs are required to respond to any significant findings with a submittal of a corrective action plan containing an analysis of the root cause, details of actions taken to resolve the issue, and strategies to prevent reoccurrence. The most common and serious problems identified during this process are presented in this paper supported by suggestions and good practices gleaned from these submittals. Opportunities for improvement are presented for each corresponding category of findings.

Introduction

The first ISO/IEC 17021 standard was published in 2006 by the International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC). It governs the requirements for Management System Certification Bodies (MSCBs). ISO and IEC develop joint ISO/IEC documents under the management of the ISO Committee on Conformity assessment (ISO/CASCO).

Certification of a management system serves as a means of providing assurance that the organization has implemented a system for the management of the relevant aspects of its activities, products and services, in line with the origination's policy and the requirements of ISO/IEC 17021-1. (1)

17021-1 specifies the requirements for certification bodies (CBs) providing audit and certification of management systems.

This paper aims to identify the main non-conformance areas that MSCBs face according to the different regions they are located, and according to the different certification disciplines they are accredited against. This study is similar to a 2019 study on testing laboratories and their non-conformity areas from different geographical regions across the world (2).

Research Methodology/Results

Data was collected from 125 MSCBs from 25 countries (Table 1). The 25 countries were then grouped into regions (Table 2) to optimize the presentation of data. Data was collected as nonconformities that were reported during the MSCB assessments. The number of nonconformities along with the clause they belonged to were recorded for each MSCB assessment. Total number of nonconformities for each clause was added to determine the clauses with the most nonconformities (Figure 4). The type of MSCB assessment from which data was gathered included initial assessments, surveillance assessments, and reassessments from 2018 to 2022.

The MSCBs were grouped into the main MSCB certification disciplines (Table 3). On average, MSCBs had three certification disciplines. Number of nonconformities along with their clauses for each of the eight specific certification disciplines were recorded (Figures 5-12). Number of nonconformities along with their clauses for each region were similarly recorded (Figures 13-17).

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(1) ISO/IEC 17021-1:2015 contains principles and requirements for the competence, consistency and impartiality of bodies providing audit and certification of all types of management systems. Certification bodies operating to ISO/IEC 17021-1:2015 do not need to offer all types of management system certification. Certification of management systems is a third-party conformity assessment activity and bodies performing this activity are therefore third-party conformity assessment bodies.

Results

Country	#MSCBs
India	26
USA	23
Turkey	16
China	13
Korea	11
Greece	4
Taiwan	4
Canada	3
Hong Kong	3
UAE	3
UK	3
Germany	2
Spain	2
Other	12

Table 1 – Number of MSCBs per country

Region	#MSCBs
Asia	58
North America	26
Europe	32
Middle East	7
Other	2

Table 2 – Number of MSCBs per region

Certification Discipline	Certification Standard
QMS (Quality)	ISO 9001
EMS (Environmental)	ISO 14001
OHSAS (Occupational)	ISO 45001
FSMS (Food Safety)	ISO 22000
FSSC (Food System)	FSSC 22000
ISMS (Information Security)	ISO/IEC 27001
MED-QMS (Medical Quality)	ISO 13485
EnMS (Energy)	ISO 50001

Table 3 – MSCB certification disciplines along with their respective standards

The requirements of ISO/IEC 17021-1 can be divided into six main categories –

- General requirements (Clause 5) – covers the legalities involved with the operation of the MSCB, and the MSCB's commitment to impartiality.
- Structural requirements (Clause 6) – covers the MSCB's organization, its management, and operations.
- Resource requirements (Clause 7) – covers competence criteria for personnel involved in the MSCB and subcontracting of personnel.

- Information requirements (Clause 8) – covers the information the MSCB makes available to the public, the certification documents it provides to the certified client, and the confidentiality agreements in place.
- Process requirements (Clause 9) – this is the largest category and covers the application submitted to the MSCB, the certification cycle, and all aspects of the audit and its outcome.
- Management system requirements (Clause 10) – covers the MSCB's procedures for control of documents, its management system manual, the management review, and internal audits. MSCB's management systems that are in accordance with ISO 9001 may chose Option B.

#	**ISO/IEC 17021-1 Clause**
5. General requirements	
5.1	Legal and contractual matters
5.2	Management of impartiality
5.3	Liability and financing
6. Structural requirements	
6.1	Organizational structure and top management
6.2	Operational control
7. Resource requirements	
7.1	Competence of personnel
7.2	Personnel involved in the certification activities
7.3	Use of individual external auditors and external technical experts
7.4	Personnel records
7.5	Outsourcing
8. Information requirements	
8.1	Public information
8.2	Certification documents
8.3	Reference to certification and use of marks
8.4	Confidentiality
8.5	Information exchange between a certification body and its clients
9. Process requirements	
9.1	Pre-certification activities
9.2	Planning audits
9.3	Initial certification
9.4	Conducting audits
9.5	Certification decision
9.6	Maintaining certification
9.7	Appeals
9.8	Complaints

9.9	Client records
10. Management system requirements for certification bodies	
10.2	Option A: General management system requirements
10.3	Option B: Management system requirements in accordance with ISO 9001

Table 4 – ISO/IEC 17021-1 clauses and requirements

For easy visualization, the data obtained from the MSCBs was represented as a series of pie charts and bar charts (Figure 1 – Figure 7).

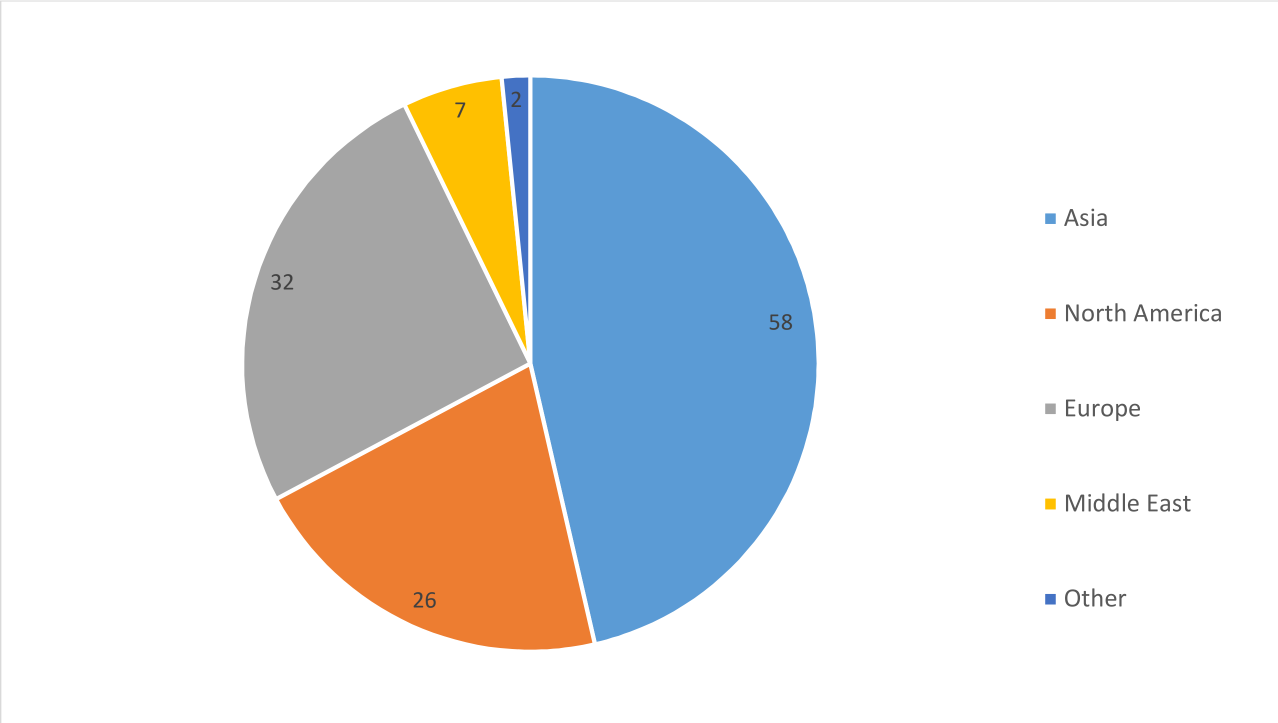

Figure 1 – Number of MSCBs per region.

The MSCBs were divided into five regions – Asia, North America, Europe, Middle East, and Other. Table 1 and Table 2 give a breakdown of which region each country belongs to. Asia had the most MSCBs, followed by North America, and Europe.

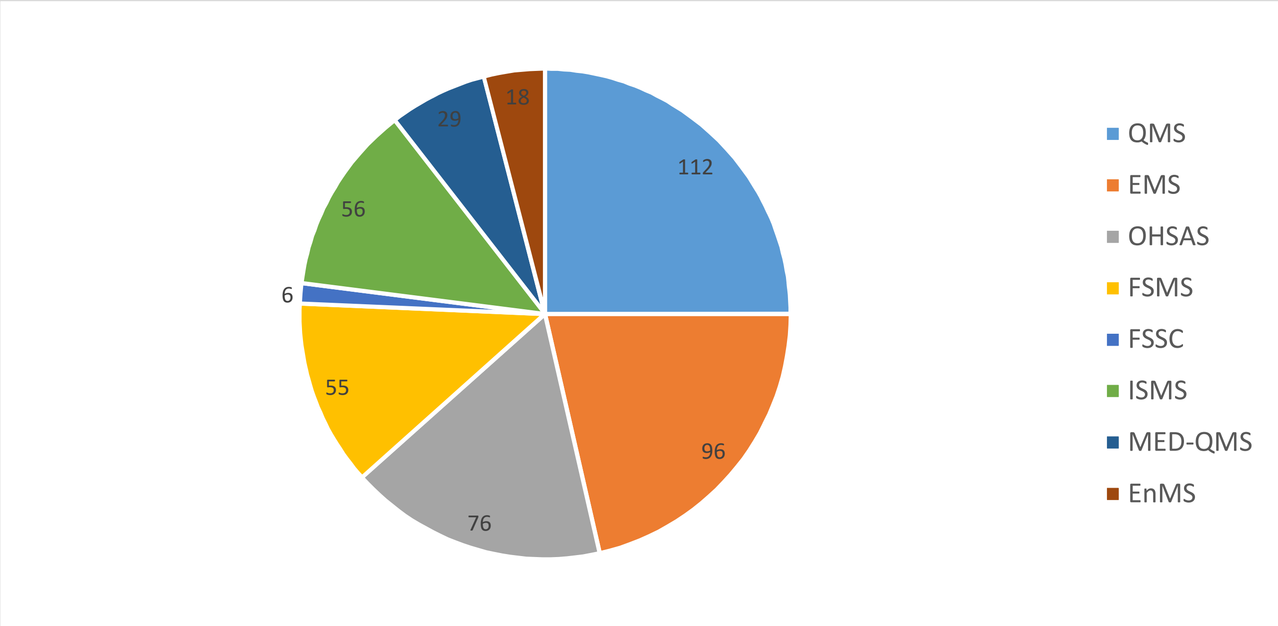

Figure 2 – MSCBs per certification discipline

The eight MSCB certification disciplines were QMS (Quality), EMS (Environmental), OHSAS (Occupational), FSMS (Food Safety), FSSC (Food System), ISMS (Information Security), MED-QMS (Medical Quality), and EnMS (Energy). The QMS discipline had the most MSCBs, followed by EMS, and OHSAS.

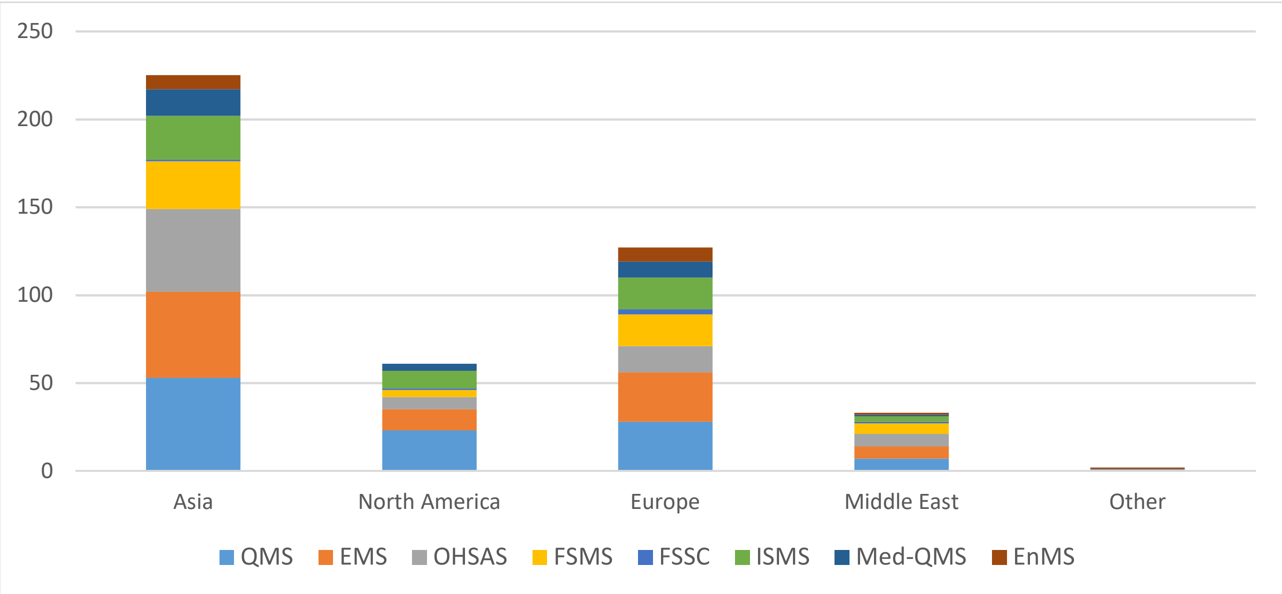

Figure 3 – Number of MSCBs per region with certification disciplines

The MSCB certification disciplines were distributed per region. Again, each region had the most MSCBS with the QMS certification discipline, followed by EMS, and OHSAS.

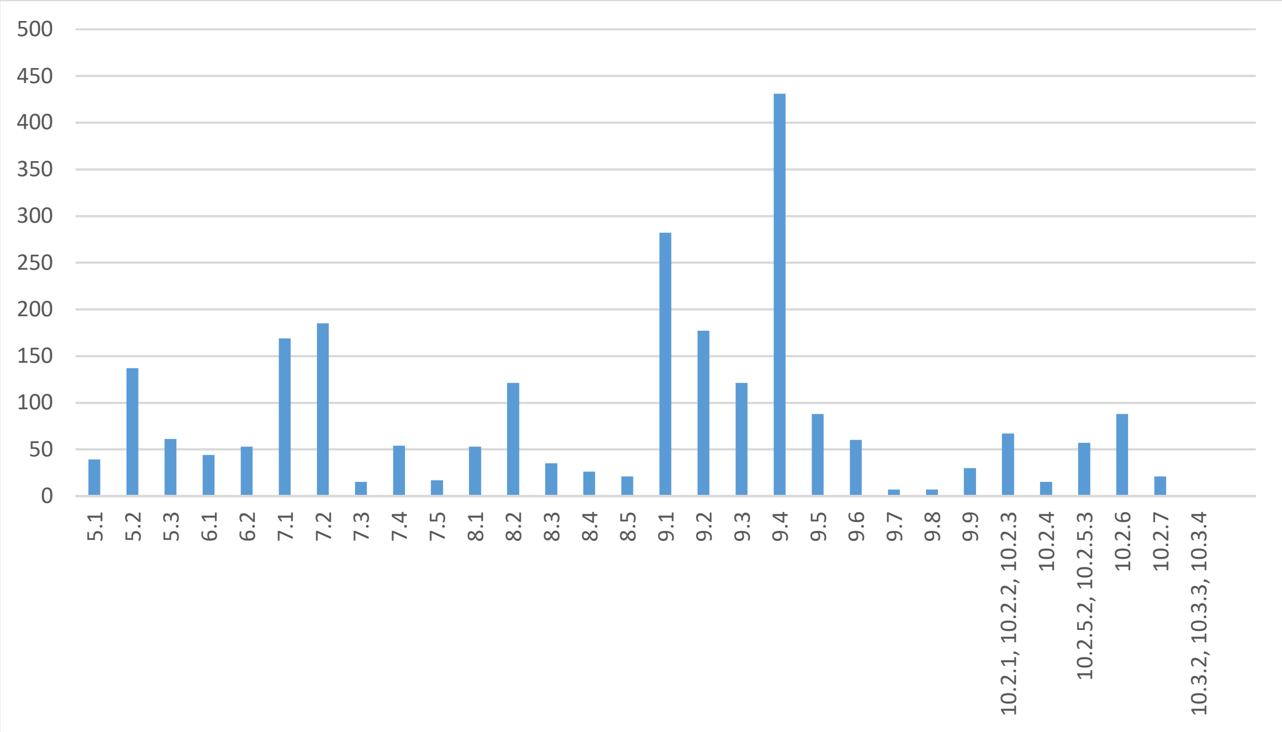

Figure 4 – Total number of nonconformities per clause for all MSCBs

The most nonconformities were observed in 9.4 Conducting audits, followed by 9.1 Pre-certification activities, 7.2 Personnel involved in the certification activities, 9.2 Planning audits, and 7.1 Competence of personnel.

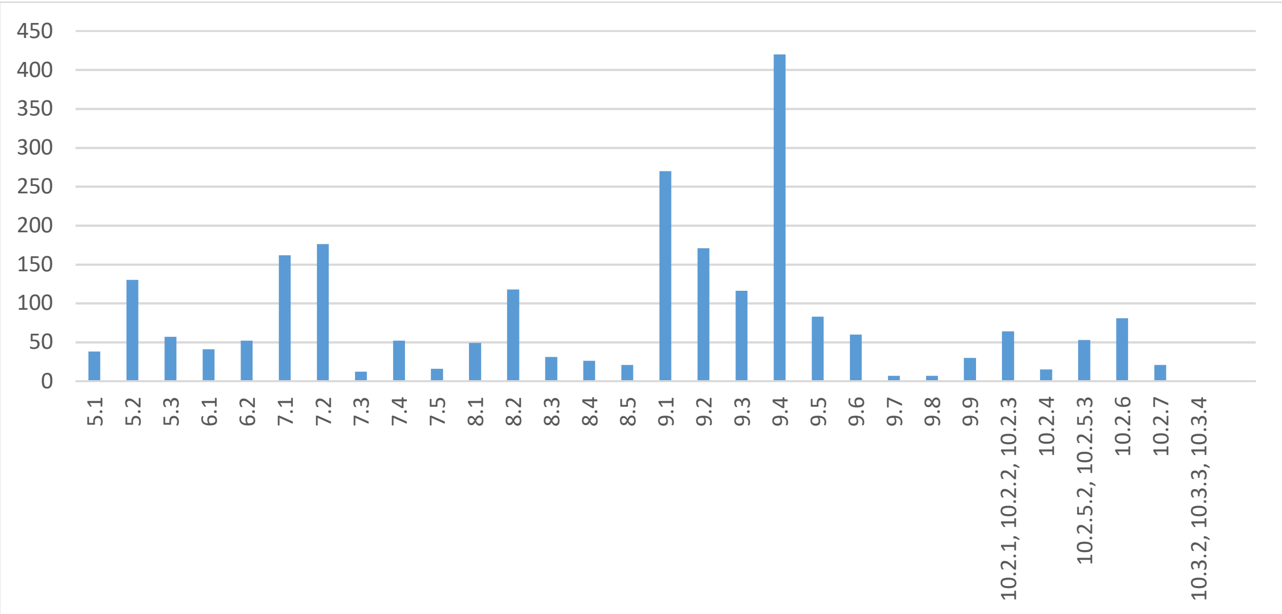

Figure 5 – Total number of nonconformities per clause for all QMS MSCBs

The most nonconformities were observed in 9.4 Conducting audits, followed by 9.1 Pre-certification activities, 7.2 Personnel involved in the certification activities, 9.2 Planning audits, and 7.1 Competence of personnel.

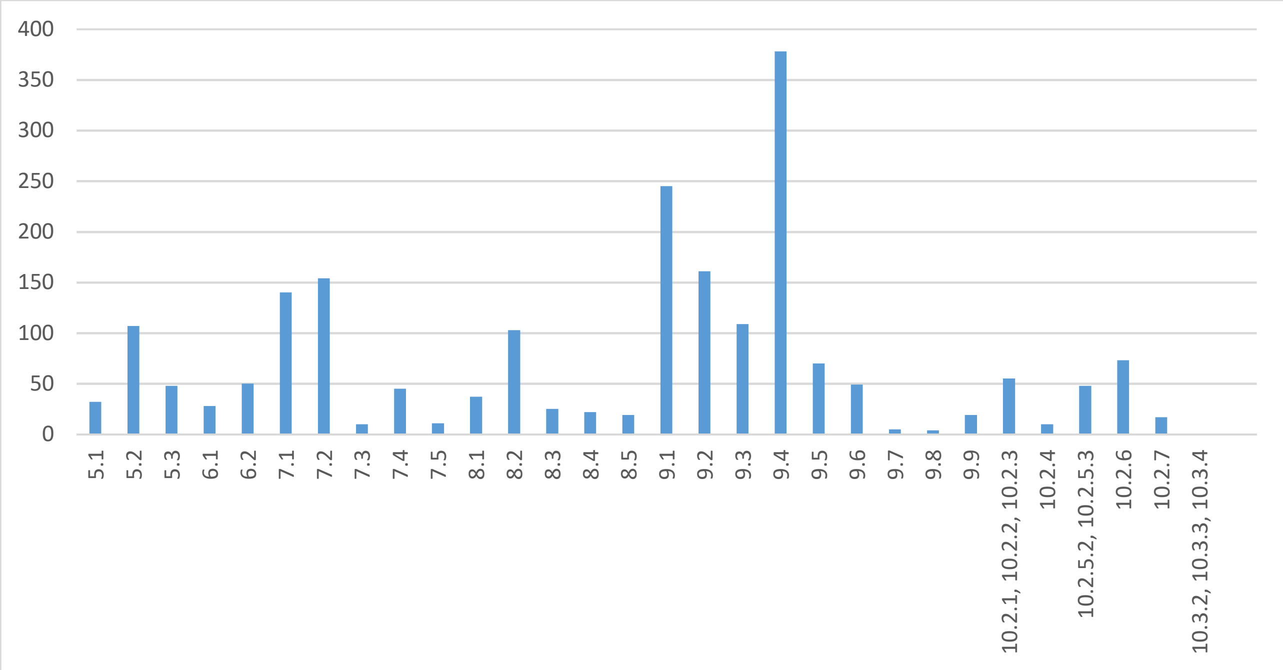

Figure 6 – Total number of nonconformities per clause for all EMS MSCBs

The most nonconformities were observed in 9.4 Conducting audits, followed by 9.1 Pre-certification activities, 9.2 Planning audits, 7.2 Personnel involved in the certification activities, and 7.1 Competence of personnel.

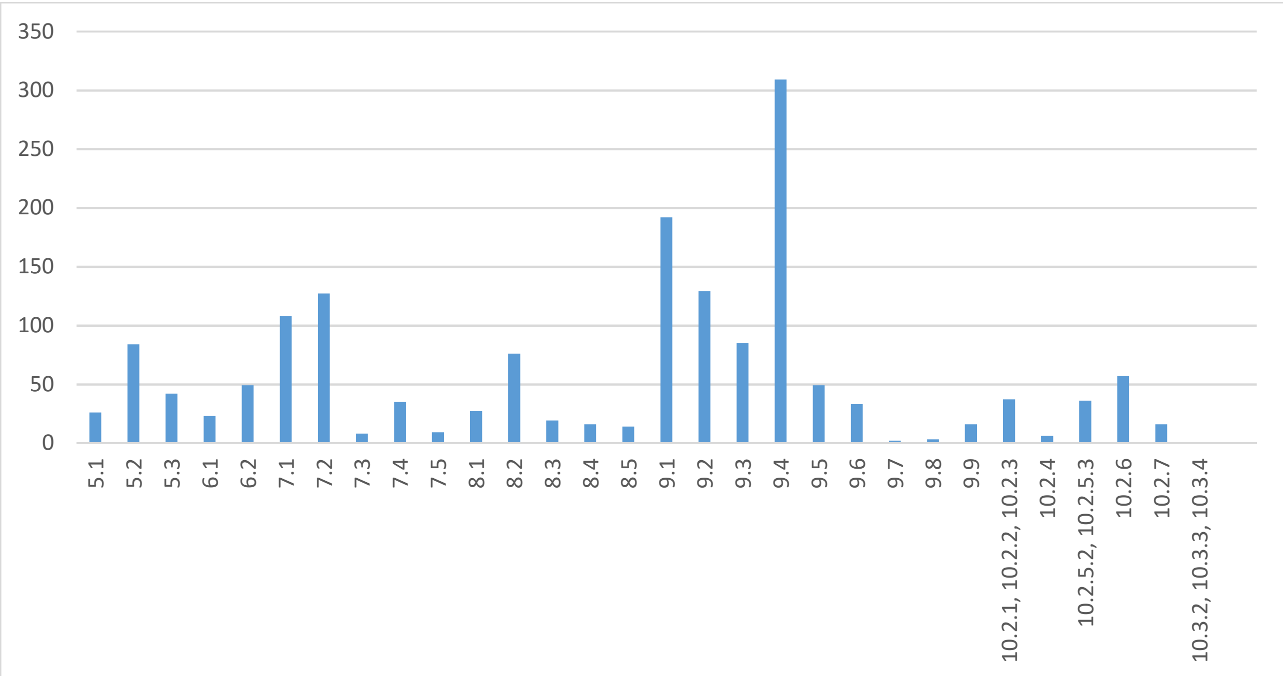

Figure 7 – Total number of nonconformities per clause for all OHSAS MSCBs

The most nonconformities were observed in 9.4 Conducting audits, followed by 9.1 Pre-certification activities, 9.2 Planning audits, 7.2 Personnel involved in the certification activities, and 7.1 Competence of personnel.

Most common and serious problems identified during auditing of MSCBs

1. Common Marketing

   Common marketing of consulting and certification services is prohibited according to cl. 5.2.9 of ISO/IEC 17021-1 - "The certification body's activities shall not be marketed or offered as linked with the activities of an organization that provides management system consultancy." It is not a typical situation when the MSCB is marketing and informing about its relations with consulting companies. However, on consulting companies' websites or marketing materials, we often see a reference to their interrelation with MSCBs which is presented as an additional benefit to get consulting from this specific consulting company. According to ISO/IEC 17021-1 it is the responsibility of the MSCB to "take action to correct inappropriate links or statements by any consultancy organization stating or implying that certification would be simpler, easier, faster or less expensive if the certification body were used".

2. Audit Techniques

   Very often auditors prefer to audit documents rather than the processes. The process approach assumes that the process outcome is the most important. If the auditor is not competent enough to understand production technology and the processes' effect on the final product, they prefer not to go to operations, and stay at the quality department auditing the quality manager. The quality manager is an important person in the company, but he doesn't create the product. It is more important to check implementation of requirements, rather than how the requirements are written in management system procedures.

3. MSCBs attempting to expand to new regions

   It is difficult and expensive to send auditors from the head office of the MSCB, and so local assessors are found to do audits in different regions. This brings a big risk of quality of work performed by remote auditors. Control of remote auditors is usually very weak and based only on assessment documents review. However, cl. 7.2.4 of ISO/IEC 17024-1 requires "The initial competence evaluation of an auditor shall include the ability to apply required knowledge and skills during audits, as determined by a competent evaluator observing the auditor conducting an audit." This means, that on-site witnessing of EVERY auditor is required BEFORE its approval for an audit.

4. Calculation of audit dates

   MSCBs try to reduce audit duration taking into consideration all reasons mentioned in IAF MD 5 to decrease audit duration, but they forget to consider factors which require increase of audit duration. In many cases, even audit duration calculation procedures do not include options of audit duration increase. For example, the COVID-19 pandemic is considered a reason to limit audit time due to reduced manufacturing, limited number of personnel in the office, and the remote nature of the audit. However, the same reasons can be considered as factors for increasing the audit duration due to interrelated risks. Many Support Departments were reorganized to operate remotely. This can lead to an increase in loss of information, limited control for OHS and environmental requirements, and simplification of operation processes by technical staff. In the case of remote audits, travel time is excluded from the audit duration. However, change of operation procedures must be assessed and effectiveness of new arrangements has to be confirmed. This need may increase audit time.

5. Certification Marks
   Very rarely does the MSCB check how the certification mark is used by certified companies. In many cases, ISO 9001 symbols are placed on the product, testing, and calibration reports.
6. Sampling and verification of information
   Sampling must be done by the auditor, not the client. The auditor should have a reasoning or logic behind the sampling made. In many cases, words cannot be considered as objective evidence (unless personnel awareness is checked). All the information provided shall be confirmed. For example, if the client says that they do not have customer feedback because their clients consider surveys annoying and do not respond to questionnaires submitted, it is expected that the auditor verifies that questionnaires WERE submitted. The auditor should not be lackadaisical in asking to provide, for example, emails which were sent to clients requesting feedback.

Conclusions

From the analysis of the data, it was evident that the top clauses in descending order with the most MSCB nonconformities overall were –

1. Conducting audits (9.4)
2. Pre-certification activities (9.1)
3. Personnel involved in the certification activities (7.2)
4. Planning audits (9.2)
5. Competence of personnel (7.1)
6. Management of impartiality (5.2)

A similar trend was also observed for most of the certification disciplines and regions.

In addition, MS certification activities continues to be the most sensitive from the point of impartiality. Comparing the MSCB accreditation program with other accreditation programs, we can conclude that the number of declined applications (failed certifications) is very limited, and we can still identify certified companies who may only formally comply to certification standards requirements, but do not follow the idea of continual improvement and achievement of quality, environmental or safety objectives. The sampling approach of MSCB activities does not allow to make claims against MSCB quality of audits, which allows them to compromise on the quality of audits for other benefits.

References

(1) International Organization for Standardization. (2015). Conformity assessment – Requirements for bodies providing audit and certification of management systems – Part 1: Requirements (ISO/IEC 17021-1:2015). Retrieved from https://www.iso.org/standard/61651.html

(2) G. I. Anastasopoulos, P. S. Ramakrishnan, I. G. Anastasopoulos, Improving Performance of Testing Laboratories – A Statistical Review and Evaluation, International Congress and Exhibition "Sustainable Civil Infrastructures", GeoMEast 2019: Sustainable Issues in Transportation Engineering pp 16-34

(3) ISO Survey of certifications to management system standards - Full results,2021. Retrieved from https://www.iso.org/the-iso-survey.html

(4) IAF MLA and Signatories, IAF site, web page: https://iaf.nu/en/recognised-abs/

(5) Facts and Figures, Table: Total Number of Accredited Conformity Assessment Bodies (CABs), ILAC site, web page: bit.ly/2ANHdBt, 2017

(6) IAS Accreditation Criteria for Management System Certification Bodies, AC477, 2020, https://bit.ly/3vBd4BY

(7) Kelly Stanton, The Risks of ISO 9001 Nonconformance, 2022, https://bit.ly/3yg5qP0

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Human-robot collaboration in a repetitive assembly process: a preliminary investigation on operator's experience and product quality outputs.

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STRUCTURED ABSTRACT

Purpose – Human-Robot Collaboration (HRC) aims to combine the skills of humans with those of robots, representing a solution to increase the quality and reconfigurability of manufacturing processes. However, to fully exploit the benefits of HRC, human factors, including the operator's psychological well-being, must be considered. To this end, this paper proposes an experimental setting aimed at exploring human-related aspects during HRC.

Design/methodology/approach – In order to explore the effects of prolonged HRC in a repetitive assembly process, a novel experimental setup concerning the production process of a tile cutter is proposed. Each participant is asked to perform three assembly shifts: two in collaborative mode with cobot support and one in manual mode. The response variables collected in the study include the quality of the interaction performed, workload, affective state of the operator and physiological indicators of stress (heart rate variability and electrodermal activity). Process defectiveness is also tracked.

Findings – Preliminary results show that HRC sessions tend to generate more stress than manual assembly sessions. However, increasing familiarity with the collaborative task tends to reduce this effect. These results are confirmed by both subjective and physiological responses.

Research limitations/implications – The evidence for the results found is limited by the number of participants involved. An experimental campaign with a larger number of participants is needed to confirm the preliminary findings.

Originality/value – This paper proposes a novel experimental study aimed at recreating a work shift in a collaborative assembly workstation of a production process. This experimental setting draws attention to the need to investigate the implications of prolonged HRC. In addition, a non-invasive biosensor is implemented to investigate the state of humans during HRC.

Keywords: Human-robot collaboration, Industry 5.0, User experience, Assembly, Manufacturing.

Paper type: Research paper

INTRODUTION

Human-Robot Collaboration (HRC) represents a solution to increase the quality, flexibility and reconfigurability of manufacturing processes (Vicentini, 2020). HRC aims to combine the skills of humans with those of robots, while also enabling physical interaction in the industrial environment (Gervasi, Mastrogiacomo, *et al.*, 2020; ISO/TS 15066:2016, 2016).

In order to effectively implement HRC is important to address the problem with an holistic view, considering both technical and human-related aspects (Gervasi, Digiaro, *et al.*, 2020; Gervasi, Mastrogiacomo, *et al.*, 2020). Over the years, the focus on human factors is becoming increasingly important (Gervasi *et al.*, 2021; Gualtieri *et al.*, 2021; Vicentini, 2020). With the recent introduction of the Industry 5.0 concept, the need to make industry human-centered has been outlined ("Industry 5.0", 2021). Human factors must be taken into account to enhance the process quality. In HRC, humans are continuously exposed to close interaction with a robotic system, resulting in possible stressful and uncomfortable situations (McColl *et al.*, 2016; Xu *et al.*, 2015; Young *et al.*, 2015). These kinds of situations can undermine the quality of production process leading to the potential generation of defects.

In order to best support the operator's well-being and improve the interaction, it is necessary to first understand the operator's psychophysical state during HRC. To investigate these aspects, feedback from classic self-assessment tools (e.g., questionnaires) is often analysed. However, such tools do not provide real-time information on the state of the operator. The introduction of physiological measures makes it possible to compensate for this limitation, while also obtaining more objective measures that can even reveal a person's unconscious states or reactions (Argyle *et al.*, 2021; Charles and Nixon, 2019).

Some previous works have focused on evaluating the operator's state in various HRC settings (Arai *et al.*, 2010; Kühnlenz *et al.*, 2018; Kulić and Croft, 2007), however studies on exploring the human's state in a prolonged interaction with a cobot in a manufacturing context are lacking. The objective of this paper is to propose an experimental setting aimed at simulating a prolonged interaction with a cobot during a repetitive assembly process. The main novel elements proposed in this study are the following:

(i) the exploration of the operator state during entire work shifts though the analysis of both subjective and physiological responses, with particular attention towards stress and workload;

(ii) the observation of process defects that can occur during prolonged HRC;

(iii) comparison of operator state between manual and HRC assembly work shifts.

The paper is organized as follows. In the next section, a review of the literature on the user experience in HRC is provided, with particular focus on the implementation of physiological measures. Next, the research methodology is provided, describing in detail the experimental setting, the equipment and materials used, and the experimental procedure. Afterwards, preliminary results of the experimental setting implementation are presented and discussed. Finally, the concluding section explores limitations and future research directions.

LITERATURE REVIEW

HRC is a paradigm characterized by several aspects, both related to the robotic system and humans (Gervasi, Mastrogiacomo, *et al.*, 2020). The introduction of collaborative robots has allowed physical interaction with people, removing barriers between the human and robot workspace. However, the removal of these barriers also introduced new potential hazards to humans, requiring an evolution of safety standards. The introduction of ISO 10218-1 and ISO 10218-2 provided guidelines on workspace design and implementation of industrial robots, identifying a list of safety hazards. The subsequent ISO/TS 15066 expanded the possibilities of HRC, allowing for the implementation of higher levels of robot autonomy in close proximity to humans.

In order to fully exploit the potential of HRC, a careful planning of the interaction is also necessary. Wang *et al.* (2019) highlighted the need for intelligent and accessible collaborative system, introducing the concept of symbiotic HRC. HRC should allow the communication through natural modes, offer an easy and intuitive programming environment to instruct the cobot, and be more immersive through the use of wearable devices (e.g., AR glasses). Inkulu *et al.* (2021) provided a review on HRC, highlighting some main challenges and opportunities. Natural modes of communication (e.g., gestures and voice) allow intuitive interaction with robots and potentially reduce idle time, but these recognition methods need to be made more robust. Power force limiting techniques are useful to efficiently collaborate with low-payload robot, however they may be not suitable for high-payload and high-speed robots which requires the implementation of additional flexible safety methods to allow collaboration with humans. More research is also needed on advanced adaptive robot systems to enhance a greater reconfigurability of production processes and reduce potential production downtime.

Recently, increased attention has been focused on human factors involved in HRC. Khalid *et al.* (2016) presented an approach for the development of safe and cyber-secure HRC in the domain of heavy payload industrial robots. Potential hazards to be taken into account were identified, including physical and mental strain due to robot behavior or collaborative task. Galin and Meshcheryakov (2020) focused on how to efficiently implement HRC, leading to the identification of the influencing factors for both cobots and humans. The perception of the robot by the human and emotional and cognitive aspects were found influential for the effectiveness of HRC.

In order to better understand and support the operator during HRC, cognitive and psycho-physical aspects should also be taken into account. Concepts like mental workload, stress, demand, strain and fatigue have been widely discussed in literature, being particularly interesting for the manufacturing context (Gawron, 2008; Wickens, 2008; Young *et al.*, 2015). Assessment of these constructs is often performed through self-reporting tools, such as the NASA-TLX (Hart and Staveland, 1988) and the Subjective Workload Assessment Technique (SWAT) (Reid and Nygren, 1988). However, this kind of tools are poorly suited to continuous monitoring in naturalistic settings, such as production lines (Marinescu *et al.*, 2018). In order to overcome these limitations, in recent years there has been an increasing focus on the implementation physiological measures for the comprehension of the operator's state (Argyle *et al.*, 2021; Bradley and Lang, 1994). So far, different works on this topic have been presented, however only few of them are focused on industrial HRC. Kulić and Croft (2007) evaluated the impact of an industrial robot motion on subjective and physiological responses (i.e., Heart Rate Variability (HRV) and ElectroDermal Activity (EDA)) with various trajectory types presented to human participants. Results revealed an increased mental stress for fast and closely passing movements, but the scenario was static in terms of interaction with the robot. Arai *et al.* (2010) conducted a similar study with an industrial manipulator, evaluating the impact of robot movement at different speeds and distances from the operator on EDA. However, also in this scenario, participants were not actively involved in the interaction with the robot. Kühnlenz *et al.* (2018) studied the impact of different trajectory profiles of a standard industrial robot on users' mental stress, assessed through HRV and EDA. Although the participant was actively involved in the task compared to other studies, there was still limited interaction with the robot.

RESEARCH METODOLOGHY

In the present study, a collaborative assembly task has been designed and implemented within the "Mind 4 Lab" (Manufacturing Industry 4.0 Laboratory) at "Politecnico di Torino" to investigate user experience, operator affective state, workload and stress in prolonged industrial HRC. The collaborative task consists in assembling a tile cutter and has been designed to recreate a typical workstation of a production cycle in an industrial context using the cobot UR3e with a collaborative gripper (

Figure 1). In order to reproduce typical working conditions of an industrial context, a set of 4-hour shifts have been implemented. Each operator is asked to perform three assembly shifts: two in collaborative mode with cobot support and one in manual mode.

Figure 1 - Collaborative robot UR3e (Mind 4 Lab, Politecnico di Torino-DIGEP).

Experimental setup

The task considered in this study concerns the assembly of a tile cutter (Figure 2). Figure 3 shows the ten components of the tile cutter and the five bolts with their respective identifiers. Before beginning the assembly task, the components are arranged on a tray as shown in Figure 4 and then the tray is placed in the work area (Figure 5). The collaborative task lasts approximately 252s, leading to the production of approximately 50 tile cutters in a 4-hour shift.

Figure 2 - Final assembly of the tile cutter (44 x 14 x 9 cm).

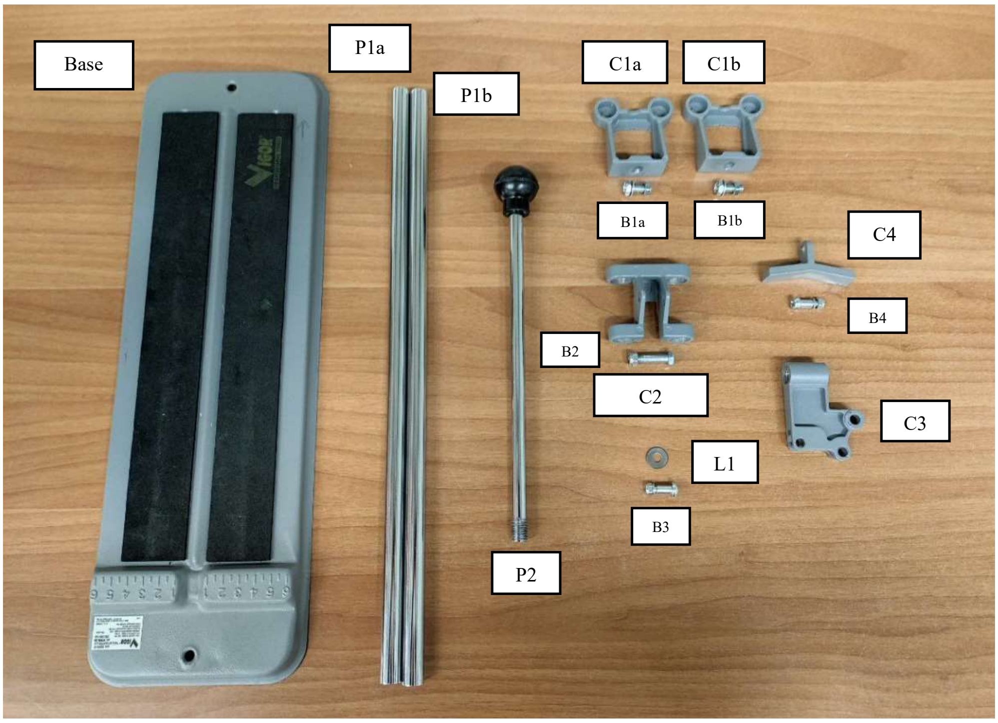


Figure 3 - Tile cutter components and bolts with their respective identifiers.

Table 1 - List of the tile cutter components with their respective identifiers.

Identifier	Component
Base	Base plate of the tile cutter.
C1a	Support for the rails of the tile cutter.
C1b	Support for the rails of the tile cutter.
B1a	Bolt for fixing the rail support to the base plate.
B1b	Bolt for fixing the rail support to the base plate.
C2	Joint component between the rails and the cutting mechanism.
B2	Bolt for joining C2 with C3.
C3	Component of the cutting mechanism.
L1	Washer blade to cut the tile.
B3	Bolt for joining the washer blade with C3.
C4	Component to break the tile.
B4	Bolt for joining C3 with C4.
P1a	Rail rod of the tile cutter.
P1b	Rail rod of the tile cutter.
P2	Handle of the tile cutter.

Figure 4 - Tray with workpieces of the tile cutter.

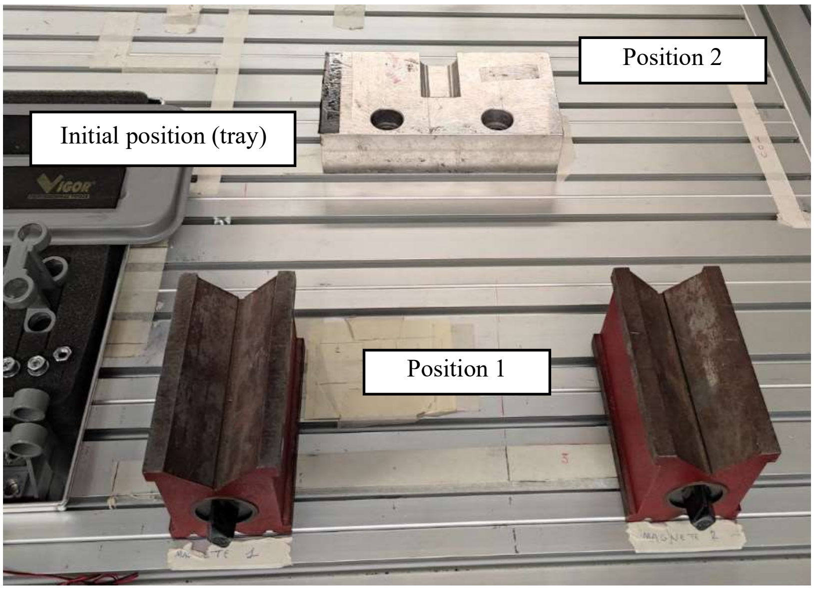


Figure 5 - Work area with reference positions used during the collaborative assembly task.

Table 2 contains the list of operations of the collaborative assembly task, which can be decomposed in four main phases:

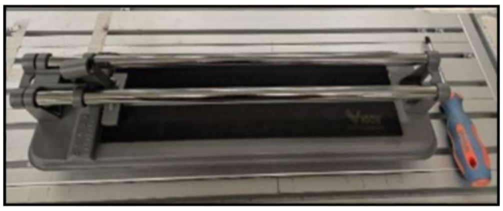
Phase 1. In the first phase, the cobot brings the base of the tile cutter closer to the operator, placing it in the assembly area, and then the operator assembles the two side supports. When the operation is finished, the cobot moves the base with the supports out of the assembly area.

Phase 2. In the second phase, the operator assembles the cutting mechanism with the support of the cobot, which holds the main component in an ergonomic position.

Phase 3. In the third phase, the cobot brings the base with supports back to the assembly area and then the operator assembles the cutting mechanism using the rods.

Phase 4. In the last phase, the operator screws the handle to the cutting mechanism, completing the assembly, and finally the cobot moves the tile cutter onto the tray.

Table 2 - Operation list of the tile cutter assembly task.

Phase	Operation	Allocation	Estimated time (s)
Phase 1: Assembling the base holders (Assembly A1). 	Op1: Moving the Base from the tray to assembly area (Position 1).	Cobot	9s
	Op2: Assembling components C1a and C1b to either side of the Base. Screwing with soft tightening of bolts B1a and B2b (Assembly A1).	Human	44s
	Op3: Moving assembly A1 out of the assembly area (Position 2).	Cobot	4s
Phase 2: Assembling the cutting mechanism (Assembly A4). 	Op4: Moving component C2 to assembly area (Position 1).	Cobot	7s
	Op5: Assembling component C3 with component C2 via bolt B2 (Assembly A2).	Human	50s
	Op6: 180° rotation of assembly A2.	Cobot	3s
	Op7: Assembling blade L1 with component C3 via bolt B3 (Assembly A3).	Human	24s
	Op8: Assembling component C4 with component C3 via bolt B4 (Assembly A4).	Human	35s
	Op9: Moving assembly A4 to the tray (Initial position).	Cobot	7s
Phase 3: Joining the cutting mechanism with the base (Assembly A6). 	Op10: Moving assembly A2 to assembly area (Position 1).	Cobot	9s
	Op11: Moving assembly A4 to assembly area (Position 1).	Human	2s
	Op12: Inserting rods P1a and P2b into holders of assembly A4 (Assembly A5).	Human	7s

	Op13: Inserting the assembly A5 into the holders of components C1a and C1b of assembly A1.	Human	14s
	Op14: Tightening the bolts B1a and B1b (Assembly A6).	Human	13s
Phase 4: Completing the tile cutter (Assembly A7). 	Op15: Screwing rod P2 into the holder of component C3 of assembly A6 (Assembly A7).	Human	13s
	Op16: Moving assembly A7 to the tray.	Cobot	11s

Equipment and materials

In order to collect the operator's feedback on his experience during the various experimental sessions, a set of self-reporting tools have been implemented. In addition to an initial questionnaire aimed at collecting demographics, the self-reporting tools considered include questionnaires on the perceived quality of interaction with the cobot, perceived workload, and affective state.

The questionnaire on interaction quality (Table 3) is based on Baraglia *et al.* (2016) and Hoffman (2019). The questionnaire is composed of 7 items, which collect participant’s perception of robot helpfulness, interaction safety and naturalness, team efficiency and fluency, comfort, and robot trustworthiness:

Q1. Robot helpfulness represents how helpful the robot is in accomplishing a certain task.
Q2. Interaction safety refers to how safe the HRC is perceived.
Q3. Interaction naturalness concerns the easiness of the interaction with the robot.
Q4. Team efficiency represents how efficient the collaboration is.
Q5. Team fluency refers to the level of coordination during the collaborative task.
Q6. Comfort represents how at ease a person feels during HRC.
Q7. Robot trustworthiness represents how reliable the robot is perceived to be during HRC.

Each item is evaluated on a 7-point Likert-scale (from “strongly disagree” to “strongly agree”) (Franceschini *et al.*, 2007).

Table 3 - Questionnaire for interaction quality.

Item No.	Questionnaire item	Dimension
Q1	The robot was helpful in accomplishing the task.	Robot helpfulness
Q2	I felt the interaction was not safe.	Interaction unsafety
Q3	The collaboration felt natural.	Interaction naturalness
Q4	The robot and I worked efficiently together.	Team efficiency
Q5	The robot and I worked fluently together.	Team fluency
Q6	I felt uncomfortable with the robot.	Discomfort
Q7	The robot was trustworthy.	Robot trustworthiness

The commonly-used NASA-TLX (Hart and Staveland, 1988) has been implemented to assess operator workload (Figure 6). It decomposes the workload in six dimensions:

- Mental demand, which represents the amount of mental and perceptual activity required by the task.
- Physical demand, referring to the amount of physical activity required by the task.
- Temporal demand, which concerns how much time pressure is perceived due to the task pace.
- Performance, referring to the degree of success and satisfaction with the results obtained in performing the task.
- Effort, which refers to how hard one had to work (mentally and physically) to achieve a certain level of performance.
- Frustration, representing the amount of irritation, stress, and annoyance felt during the task.

Each dimension is rated on a 0-100 scale with 5-point steps (see Figure 6), and the final workload score is obtained by averaging the dimension ratings.

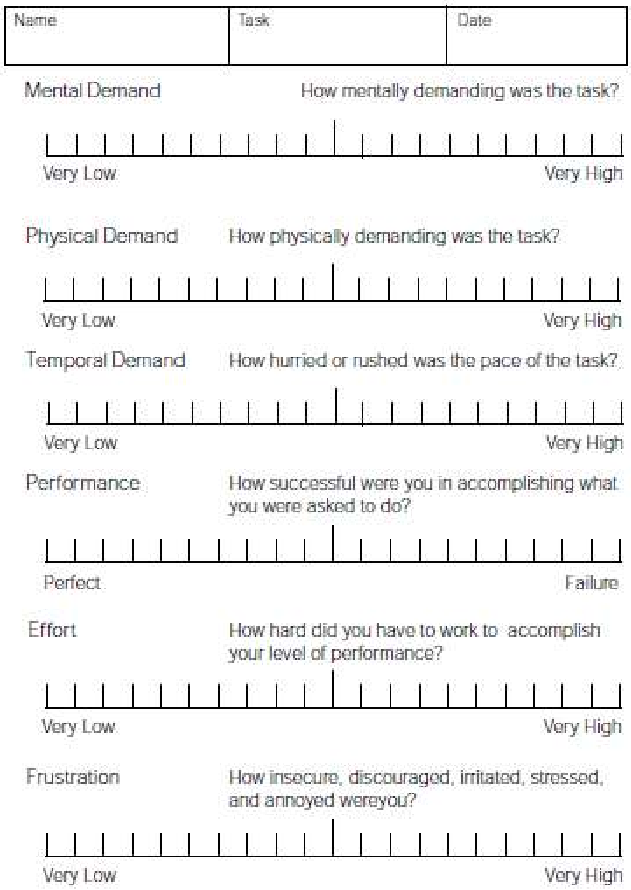


Figure 6 - NASA-TLX questionnaire (Hart and Staveland, 1988).

The SAM (Bradley and Lang, 1994; Lang, 1980) is a widely used image-based assessment tool to measure the affective reaction to a certain situation or event. It is based on the Pleasure-Arousal-Dominance (PAD) model, which represents affective states on three dimensions:

- Valence (or pleasure), which describes the positivity or negativity of an elicited emotion (e.g., fear, anger, or boredom tend to be negative emotions, whereas relaxation or joy tend to be positive emotions).
- Arousal, which refers to how excited a person is, regardless of whether the excitement derives from a positive or negative emotion (e.g., boredom and relaxation are characterized by low arousal, whereas euphoria, fear, or anger tend to have a high arousal).
- Dominance, which describes how much one feels in control of a situation, i.e., a feeling of control and influence over one's surroundings and others (e.g., fear or anxiety are usually characterized by low dominance, while relaxation or anger by a high dominance).

Figure 7 shows the original 9-point scale SAM, which has been used in the study to collect affective state of the participants during the experimental sessions.

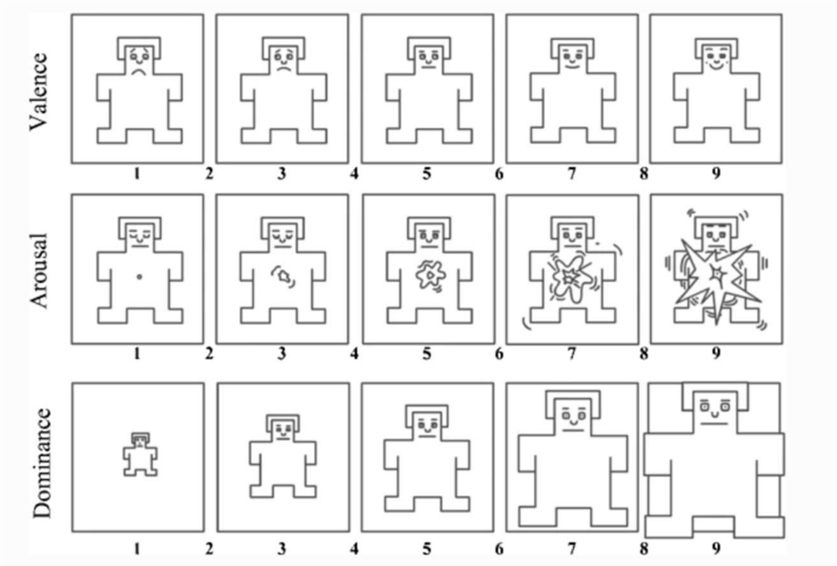


Figure 7 - Self-Assessment Manikin (SAM) with its three dimensions for affective state: valence, arousal, and dominance (Bradley and Lang, 1994).

In addition to classical self-reporting tools, the Empatica E4 wristband (Figure 8) has also been used to obtain a measure of physiological stress. This non-invasive biosensor allows to collect EDA data at 4Hz, heart data through Photopletismogram (PPG) at 64Hz, and 3-axis accelerometer data at 32Hz. The device also provides the heart rate NN-intervals. PPG and EDA data are used as arousal and stress indicators, evaluating HRV and average Skin Conductance Response (SCR) in each experimental session.

Figure 8 - The Empatica E4 biosensor (“Empatica”).

EDA data are processed using the MATLAB-based software “Ledalab”. Continuous Decomposition Analysis (CDA) (Benedek and Kaernbach, 2010) is performed to decompose the EDA signal into continuous signals of phasic and tonic activity. Tonic activity refers to long-term fluctuations in EDA that are not specifically elicited by external stimuli and is best characterized by changes in Skin

Conductance Level (SCL). In contrast, phasic activity refers to short-term fluctuations in EDA which have been elicited by a usually identified and externally presented stimulus. Through the analysis of the phasic activity signal, Skin Conductance Responses (SCRs) (i.e., amplitude changes from the SCL to a peak of the response) can be identified. In this study, the average SCR is used as an arousal and stress indicator in each experimental session. From heart data, HRV measures can be derived and used as an arousal and stress indicator. In this study, the Root Mean Square of Successive Differences between adjacent NN-intervals (RMSSD) was considered as measure of HRV due to its common use (Kim *et al.*, 2018; Young *et al.*, 2015).

Experimental procedure

Figure 9 reports the flowchart of an experimental session. After explaining the objectives of the study and its procedure, the participant is seated in the experiment location and the various steps of the assembly task are presented. Afterwards, the Empatica E4 biosensor is firmly placed on the participant's left wrist and 15 minutes are waited for the electrodes to adhere well to the skin and to obtain reliable EDA data. The participant is asked to fill the initial questionnaire, which includes demographics. Next, the participant is invited to relax and remain still to record 2 minutes of physiological signals at rest (i.e., the baseline of the physiological signals). After this phase is completed, the participant begins the 4-hour shift of the assembly task. In order to simulate realistic working conditions, within the shift a 10-minute break is provided every two hours of work. During the work shift, another operator supervises each session by taking note of occurring process defects. At the end of the work shift, the participant reports his affective state during the task through the SAM, fills the NASA-TLX and the questionnaire on the quality of interaction with the cobot. At the conclusion of the session, the participant is asked for general unstructured feedback about the overall experience. Each participant performs three assembly shifts: two in collaborative mode with cobot support and one in manual mode. In manual assembly, the interaction quality questionnaire is not administered.

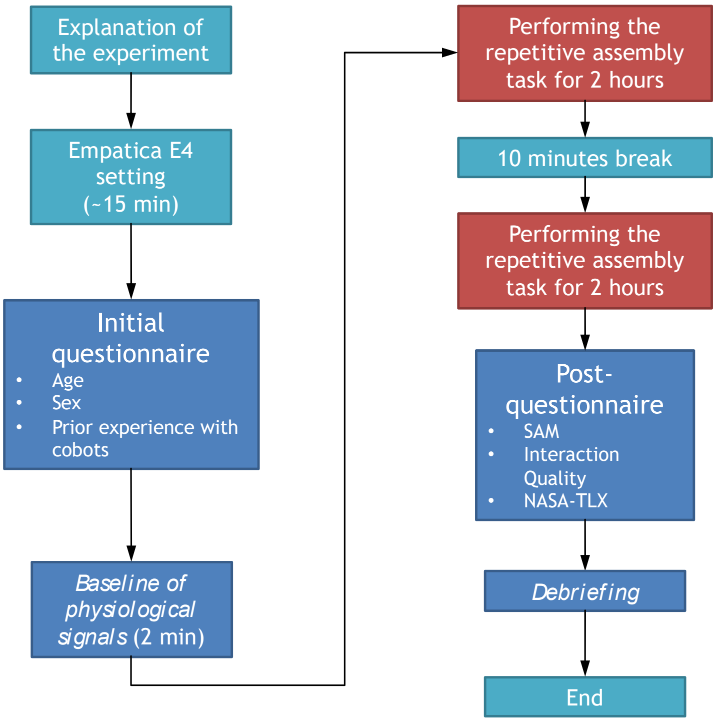


Figure 9 - Flow-chart of the experimental session (4-hour shift).

PRELIMINARY RESULTS

In order to test the proposed experimental setting, a participant with no previous experience interacting with a cobot was involved. The participant performed two collaborative assembly sessions and one manual assembly session. This allowed us to compare potential differences in response variables between two HRC assembly sessions and between a manual assembly session with an HRC one. Preliminary results obtained are reported in the following subsections.

Prolonged HRC interaction

In order to explore the effects on prolonged HRC assembly sessions, two 4-hour shifts has been carried out. Figure 10 shows the scores obtained on the various dimensions of the interaction quality questionnaire. Interestingly, in the first session the interaction with the cobot was not perceived as particularly fluid and natural (3-"somewhat disagree"), however the perception of these aspects improved significantly at the end of the second session leading to a positive evaluation. This result denotes a learning effect intrinsic to repetitive interactions with the cobot.

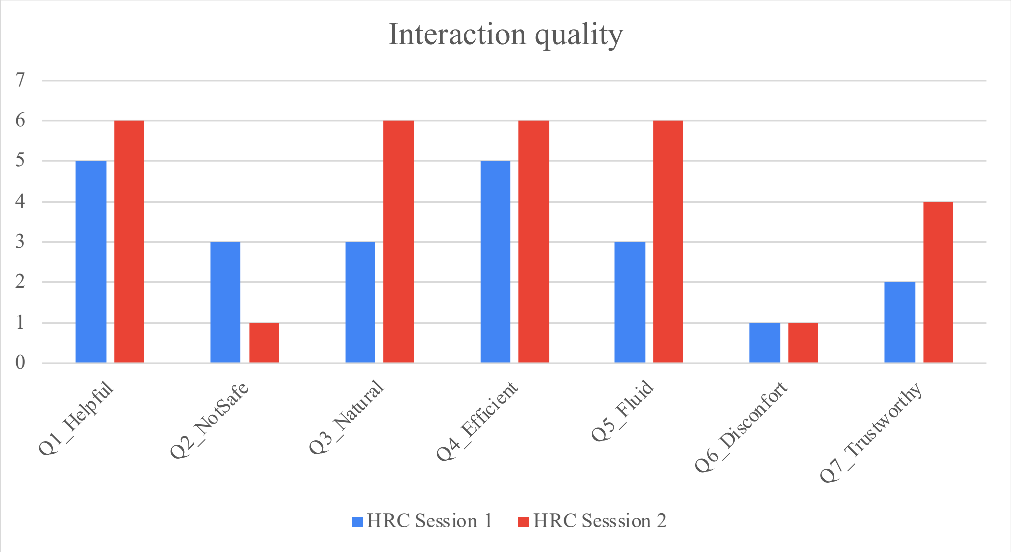


Figure 10 - Comparison of interaction quality ratings between the first HRC assembly session and the second one.

Regarding the perceived workload, from Figure 11 it can be noticed a decrease from the first HRC session to the second one. This is mainly due to a significant decrease in the *Effort* and *Frustration* dimensions, highlighting a greater familiarity with the collaborative task. A further decrease in perceived workload is present in the manual assembly session. In this case, the absence of the robot increased the perception of physical effort, however mental effort and frustration decreased significantly. This initial finding highlights a possible psychological influence of the cobot on operator stress.

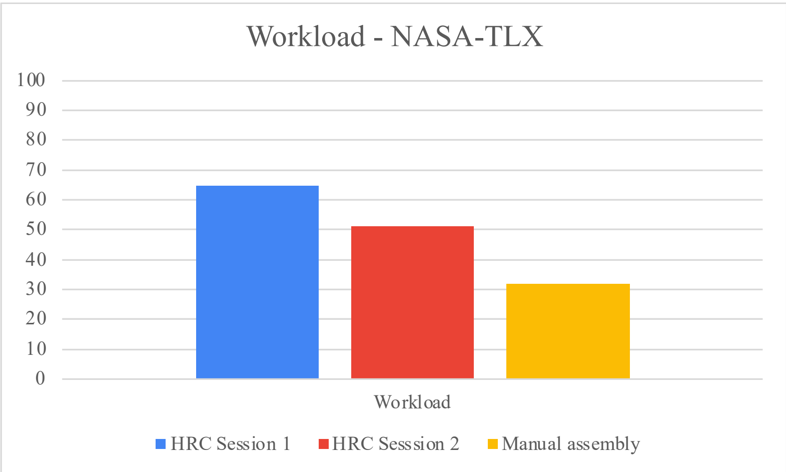


Figure 11 - Comparison of workload scores of NASA-TLX between the three experimental sessions.

Figure 12 shows the affective state during the three sessions. An interesting decrease in arousal can be seen between the first HRC session and the second session which suggests a potential decrease in stress. A further decrease in arousal can be observed in the manual assembly session. In addition, the absence of the cobot also led to a greater sense of dominance of the situation by the operator.

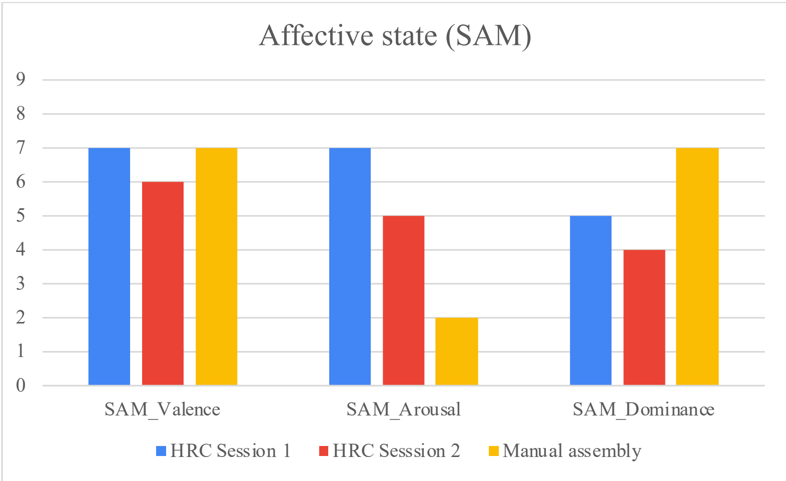


Figure 12 - Comparison of SAM dimensions ratings between the three experimental sessions.

A confirmation of these effects can be found in the physiological responses (HRV and EDA). From the Figure 13 a similar trend to that of arousal can be seen for HRV and average of SCRs. Lower heart rate variability (i.e., lower RMSSD) is associated with higher operator stress, while a higher average of SCRs is associated with higher operator stress. A consistent decrease in stress can be seen between the first and second HRC sessions, highlighting the importance of familiarity with the collaborative task. However, a further decrease in stress can be observed in the manual assembly session, due to the absence of the cobot in the task.

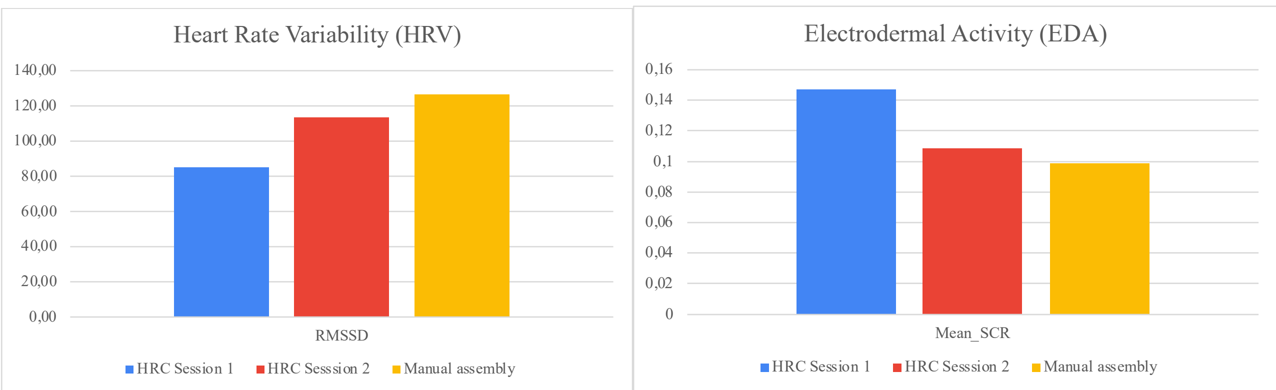


Figure 13 - Comparison of physiological stress indicators (RMSSD for HRV and average of SCRs for EDA) in the three experimental sessions.

Figure 14 shows an example of a 2-hour EDA signal during the first HRC session. As can be seen, the actions of the robot have caused an instantaneous increase in EDA and this effect has sometimes persisted over time with a general increase in the trend of the signal. This increase in trend is also indicative of an increase in cognitive effort on the part of the operator. Such situations were found especially in HRC sessions.

Figure 15 illustrates the process defectiveness detected during the various experimental sessions. Examples of process defects include falling tools, components, screws or nuts, and incorrect picking or assembly of components with self-correction of the defect. During the first HRC session, the highest number of defects were observed, mainly due to falling parts or incorrect assembly of components. The lowest number of defects was observed in the manual assembly session. It is possible to note that most of the defects were observed in the presence of greater operator's stress (Figure 13).

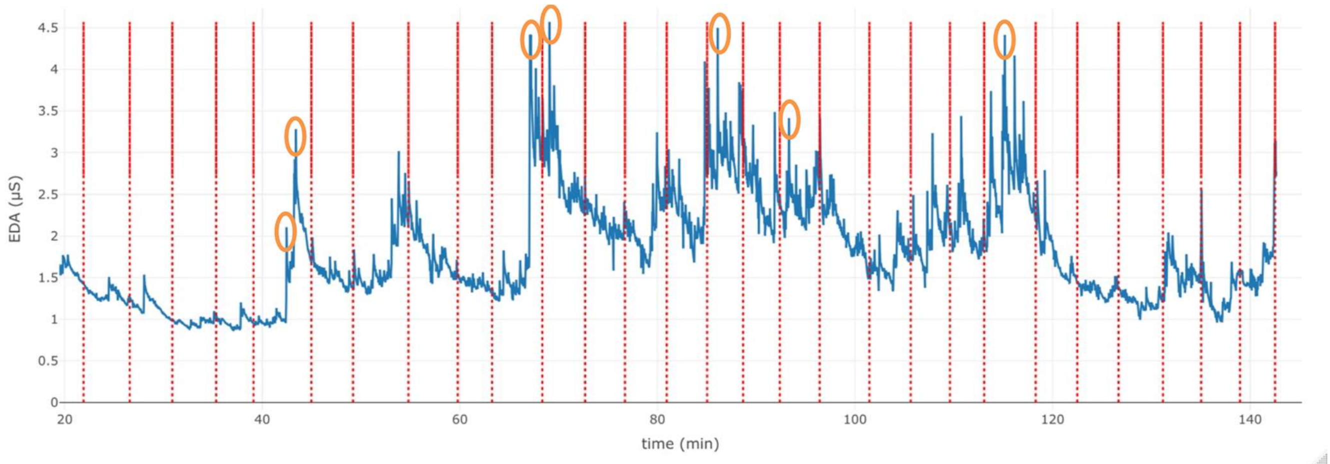


Figure 14 - Example of a 2-hour EDA signal during an HRC session. The peaks highlighted (SCRs) can be attributed to actions of the cobot that generated stress in the operator. Dashed vertical lines separate the various assembly tasks of the tile cutter.

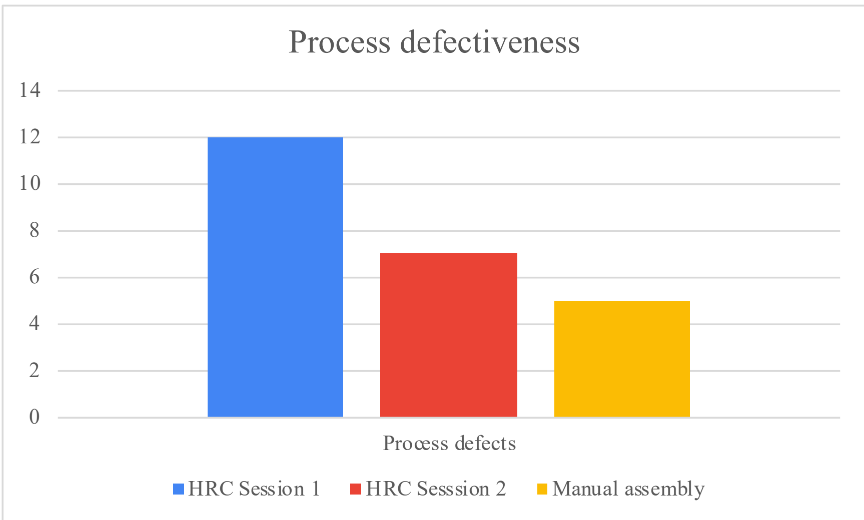


Figure 15 - Comparison of process defectiveness between the three experimental sessions.

DISCUSSION AND CONCLUSIONS

In this paper, a novel experimental setting is proposed in order to reproduce a set of 4-hour work shifts of a repetitive collaborative assembly task. Through the implementation of this setting, it is possible to conduct studies on the effects of a prolonged interaction with a cobot on human state and process defect in a manufacturing context. Moreover, thanks to the integration of non-invasive biosensors, it is possible to obtain objective information on the psychophysical state of the operator without interfering with the task. The objective is to investigate operator experience and stress in relation to HRC in repetitive tasks, as well as defect generation. As highlighted in the concept of Industry 5.0, the human being is an integral part of production processes and the improvement of his well-being and enhancement has significant implications on the quality of processes and products. The preliminary results obtained show the importance of familiarity with the collaborative task in order to preserve human well-being and improve the quality of interaction. However, it has also emerged that interaction with the cobot can introduce more cognitive stress than a classical manual setting, although it lightens the physical workload of the operator. This first result highlights the importance of also taking into account psycho-cognitive aspects when introducing a collaborative robotic system in a workstation in order to obtain the maximum benefit from HRC. It could also be noted that increased operator stress resulted in more process defects, however this phenomenon requires further investigation.

A limitation of the proposed experimental setting is represented by the time resources required for its implementation; however, they prove necessary in longitudinal studies, especially when investigating long-term effects of HRC. A limitation of this study is the preliminary nature of the reported results. Future studies will focus on expanding our findings by increasing the sample of participants and further exploring the phenomena involved.

AKNOWLEDGEMENTS

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REFERENCES

Arai, T., Kato, R. and Fujita, M. (2010), “Assessment of operator stress induced by robot collaboration in assembly”, *CIRP Annals*, Vol. 59 No. 1, pp. 5–8.

Argyle, E.M., Marinescu, A., Wilson, M.L., Lawson, G. and Sharples, S. (2021), “Physiological indicators of task demand, fatigue, and cognition in future digital manufacturing environments”, *International Journal of Human-Computer Studies*, Vol. 145, p. 102522.

Baraglia, J., Cakmak, M., Nagai, Y., Rao, R. and Asada, M. (2016), "Initiative in robot assistance during collaborative task execution", *2016 11th ACM/IEEE International Conference on Human-Robot Interaction (HRI)*, pp. 67–74.

Benedek, M. and Kaernbach, C. (2010), "A continuous measure of phasic electrodermal activity", *Journal of Neuroscience Methods*, Vol. 190 No. 1, pp. 80–91.

Bradley, M.M. and Lang, P.J. (1994), "Measuring emotion: The self-assessment manikin and the semantic differential", *Journal of Behavior Therapy and Experimental Psychiatry*, Vol. 25 No. 1, pp. 49–59.

Charles, R.L. and Nixon, J. (2019), "Measuring mental workload using physiological measures: A systematic review", *Applied Ergonomics*, Vol. 74, pp. 221–232.

"Empatica". *Empatica*, available at: https://www.empatica.com/research/e4 (accessed 13 April 2022).

Franceschini, F., Galetto, M. and Maisano, D. (2007), *Management by Measurement*, Springer, Berlin, Heidelberg, available at:https://doi.org/10.1007/978-3-540-73212-9.

Galin, R.R. and Meshcheryakov, R.V. (2020), "Human-Robot Interaction Efficiency and Human-Robot Collaboration", in Kravets, A.G. (Ed.), *Robotics: Industry 4.0 Issues & New Intelligent Control Paradigms*, Springer International Publishing, Cham, pp. 55–63.

Gawron, V.J. (2008), *Human Performance, Workload, and Situational Awareness Measures Handbook*, 2nd ed., CRC Press, Boca Raton, available at:https://doi.org/10.1201/9781420064506.

Gervasi, R., Digiaro, F., Mastrogiacomo, L., Maisano, D. and Franceschini, F. (2020), "Comparing quality profiles in Human-Robot Collaboration: empirical evidence in the automotive sector", *Proceedings Book of the 4th International Conference on Quality Engineering and Management*, University of Minho, Portugal, pp. 89–114.

Gervasi, R., Mastrogiacomo, L. and Franceschini, F. (2020), "A conceptual framework to evaluate human-robot collaboration", *The International Journal of Advanced Manufacturing Technology*, Vol. 108 No. 3, pp. 841–865.

Gervasi, R., Mastrogiacomo, L., Maisano, D.A., Antonelli, D. and Franceschini, F. (2021), "A structured methodology to support human–robot collaboration configuration choice", *Production Engineering*, available at:https://doi.org/10.1007/s11740-021-01088-6.

Gualtieri, L., Rauch, E. and Vidoni, R. (2021), "Emerging research fields in safety and ergonomics in industrial collaborative robotics: A systematic literature review", *Robotics and Computer-Integrated Manufacturing*, Vol. 67, p. 101998.

Hart, S.G. and Staveland, L.E. (1988), "Development of NASA-TLX (Task Load Index): Results of Empirical and Theoretical Research", in Hancock, P.A. and Meshkati, N. (Eds.), *Advances in Psychology*, Vol. 52, North-Holland, pp. 139–183.

Hoffman, G. (2019), "Evaluating Fluency in Human–Robot Collaboration", *IEEE Transactions on Human-Machine Systems*, presented at the IEEE Transactions on Human-Machine Systems, Vol. 49 No. 3, pp. 209–218.

"Industry 5.0". *European Commission - European Commission*, Text, , available at: https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (accessed 20 August 2021).

Inkulu, A.K., Bahubalendruni, M.V.A.R., Dara, A. and K., S. (2021), "Challenges and opportunities in human robot collaboration context of Industry 4.0 - a state of the art review", *Industrial Robot: The International Journal of Robotics Research and Application*, Vol. ahead-of-print No. ahead-of-print, available at:https://doi.org/10.1108/IR-04-2021-0077.

ISO 10218-2:2011. (2011), *Robots and Robotic Devices – Safety Requirements for Industrial Robots – Part 2: Robot Systems and Integration*, Standard No. ISO 10218-2:2011, International Organization for Standardization, Geneva, CH, available at: https://www.iso.org/standard/41571.html.

ISO/TS 15066:2016. (2016), *Robots and Robotic Devices – Collaborative Robots*, Standard No. ISO/TS 15066:2016, International Organization for Standardization, Geneva, CH, available

at: https://www.iso.org/standard/62996.html.
Khalid, A., Kirisci, P., Ghrairi, Z., Thoben, K.-D. and Pannek, J. (2016), “A methodology to develop collaborative robotic cyber physical systems for production environments”, *Logistics Research*, Vol. 9 No. 1, p. 23.
Kim, H.-G., Cheon, E.-J., Bai, D.-S., Lee, Y.H. and Koo, B.-H. (2018), “Stress and Heart Rate Variability: A Meta-Analysis and Review of the Literature”, *Psychiatry Investigation*, Vol. 15 No. 3, pp. 235–245.
Kühnlenz, B., Erhart, M., Kainert, M., Wang, Z.-Q., Wilm, J. and Kühnlenz, K. (2018), “Impact of trajectory profiles on user stress in close human-robot interaction”, *at - Automatisierungstechnik*, De Gruyter, Vol. 66 No. 6, pp. 483–491.
Kulić, D. and Croft, E. (2007), “Physiological and subjective responses to articulated robot motion”, *Robotica*, Cambridge University Press, Vol. 25 No. 1, pp. 13–27.
Lang, P.J. (1980), “Behavioral treatment and bio-behavioral assessment: Computer applications”, in Sidowski, J.B., Johnson, J.H. and Williams, T.A. (Eds.), *Technology in Mental Health Care Delivery Systems*, Norwood, NJ: Ablex, pp. 119–137.
“Ledalab”. available at: http://www.ledalab.de/ (accessed 23 June 2021).
Marinescu, A.C., Sharples, S., Ritchie, A.C., Sánchez López, T., McDowell, M. and Morvan, H.P. (2018), “Physiological Parameter Response to Variation of Mental Workload”, *Human Factors*, SAGE Publications Inc, Vol. 60 No. 1, pp. 31–56.
McColl, D., Hong, A., Hatakeyama, N., Nejat, G. and Benhabib, B. (2016), “A Survey of Autonomous Human Affect Detection Methods for Social Robots Engaged in Natural HRI”, *Journal of Intelligent & Robotic Systems*, Vol. 82 No. 1, pp. 101–133.
Reid, G.B. and Nygren, T.E. (1988), “The Subjective Workload Assessment Technique: A Scaling Procedure for Measuring Mental Workload”, in Hancock, P.A. and Meshkati, N. (Eds.), *Advances in Psychology*, Vol. 52, North-Holland, pp. 185–218.
Vicentini, F. (2020), “Collaborative Robotics: A Survey”, *Journal of Mechanical Design*, Vol. 143 No. 040802, available at:https://doi.org/10.1115/1.4046238.
Wang, L., Gao, R., Váncza, J., Krüger, J., Wang, X.V., Makris, S. and Chryssolouris, G. (2019), “Symbiotic human-robot collaborative assembly”, *CIRP Annals*, Vol. 68 No. 2, pp. 701–726.
Wickens, C.D. (2008), “Multiple Resources and Mental Workload”, *Human Factors*, SAGE Publications Inc, Vol. 50 No. 3, pp. 449–455.
Xu, D., Wu, X., Chen, Y.-L. and Xu, Y. (2015), “Online Dynamic Gesture Recognition for Human Robot Interaction”, *Journal of Intelligent & Robotic Systems*, Vol. 77 No. 3, pp. 583–596.
Young, M.S., Brookhuis, K.A., Wickens, C.D. and Hancock, P.A. (2015), “State of science: mental workload in ergonomics”, *Ergonomics*, Taylor & Francis, Vol. 58 No. 1, pp. 1–17.

Total Quality Management Philosophy Within the Fourth Industrial Revolution Towards Sustainability: A State-of-The-Art Literature Review and A Proposed Protocol for Further Research

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STRUCTURED ABSTRACT

Purpose - This article aims to discuss means and concepts of adapting Total Quality Management (TQM) within the Fourth Industrial Revolution 4.0 (I4.0) to achieve sustainability and organizational excellence that will guide industries into this new technological era. The present paper proposes a model of an ecosystem that guides the implementation of quality management through integrating I 4.0 technologies, quality, and sustainability in industrial settings.

Design/methodology/approach - This is an article that uses a systematic review of the literature to develop a bibliographic foundation and recommendations on the integration of Total Quality Management (TQM) and I4.0 technologies, as well as the measurement of sustainability. A state-of-the-art literature Review was performed to compile a list of scientifically significant papers that would serve as a source for data sets and content analysis.

Findings - The findings indicate that when quality management is adapted to I4.0 technologies, an ecosystem is created that facilitates the integration of technology, Total Quality Management, and people in an industrial setting and successfully contributes to achieving sustainability.

Research limitations/implications - This article does a systematic evaluation of the literature. Still, it avoids digging into concerns such as distinct economic sectors and the cultures of nations having industries that can be included, which are the research's limits.

Keywords: Total Quality Management, Industry 4.0, Sustainability, State-Of-The-Art.

Paper type: Literature review.

INTRODUTION

In modern manufacturing settings, characterized by highly competitive environments and tight government regulations towards sustainability, adopting the best of management philosophies would give organizations a competitive advantage and the agility to overcome the challenges they face. We now live in an era defined by "Industry 4.0" as the primary engine of production. Industry 4.0 is a term that alludes to the fourth industrial revolution, which requires a comprehensive and dynamic change in how business, production, and manufacturing are conducted and executed (Tortorella, Giglio and van Dun, 2019). This global technology's wave is reshaping manufacturing industries and production processes.

The competition to acquire more market shares has put pressure on organizations to upgrade their current manufacturing operations and practices to more advanced levels by exploiting the emerging technologies of Industry 4.0. The new manufacturing systems are now smarter, more intelligent, flexible, digital, agile, and well-equipped to confront market volatility and keep up with the evolution of international markets. Global manufacturing industries have seen a huge change with the advent of Industry 4.0 technologies such as cloud computing, big data analytics, robotic systems, and the Internet of Things (Oztemel and Gursev, 2020). Industry 4.0 technologies play a critical role in manufacturing industries and their sustainability performance, bringing about enhanced machinery, improved communication technology, reduced lead times, improved working environments, and competitive product quality. The three major drivers of I 4.0 represented by connectivity, intelligence, and automation introduces impressive changes in the way enterprises and manufacturing organizations should be operating in a globalized world and altering product life cycle (Radziwill, 2020).

Total Quality Management (TQM) is a management strategy that is widely used by manufacturing and service organizations to improve organizational performance and achieve customer satisfaction and delight (Zairi, 2020). It is defined by the ASQ (2020), as "an integrated approach to achieving and sustaining high quality output" which involves "all levels of functions of the organization." Total quality management is structured around a set of quality management fundamental concepts, operational practices, tools, and techniques with the objective of providing customer with high-quality products and services. TQM has been successfully implemented in manufacturing, service, and public-sector organizations. Successful case studies have been reported in the open literature, which spans manufacturing, mining, food industries, healthcare, education, and finance, among many others (Zairi, 1991).

Sustainable development is a new, accelerating, and emerging trend that is important to all humanity. We are enjoying a higher quality of life, driven by rapid economic growth. But at the same time, we need to deal with serious environmental degradation (pollution, global warming, etc.) and social problems (poverty, diseases, inequity, etc.). Sustainability is the key imperative in modern life. Great efforts have been made by international organizations (UN) and national governments to ensure a better quality of life and to protect the environment through laws, action plans, and initiatives (de Sousa Jabbour et al., 2018). These regulations put more emphasis on manufacturing and industries' adopting sustainability concepts through the whole product life cycle. Sustainability assessments and maturity models have been used to analyze potential environmental impacts associated with all stages of product life, from raw materials extraction to the use of the product by the end user and consumer and its disposal after.

Technology is sometimes claimed not to be the primary driver of digital transformation, but rather a piece in the complicated puzzle that enterprises must solve to remain competitive in an increasingly digital environment. In this context, we argue for the significance of considering the consequences of digital technologies on total quality management (Nicoletti Junior and Oliveira, 2019). It has been asserted that there has been little innovation in the field of total quality management in the context of digital transformation. However, the fact is that there has been a lively debate in this scientific and professional community, one that has frequently centered around the branding of "Total Quality Management 4.0" (Stamenkov and Dika, 2019). Total quality management professionals and researchers focus on concepts, strategies, methodologies, and total quality management tools in this rapid transformation called the Fourth Industrial Transformation (Sader, Husti and Daróczi, 2019).

Saudi Arabia launched its national Vision 2030, with the aim to achieve a leading position in the global economy, through a series of programs to diversifying economic sectors, localizing strategic industries such as mining, renewable energy and military industries. The National Industrial Development and Logistics Program (NIDLP) was launched as one of the vision realization programs, with the aim of transforming the Kingdom of Saudi Arabia into a leading industrial power and a global logistics centre in promoting the growth of its manufacturing sectors with a strong focus on the technologies of the Fourth Industrial Revolution (Industry 4.0), together with adopting best practices of Total Quality Management. So, the Saudi manufacturing companies are required to operate in a completely new technological environment and should build their capabilities to compete at the local and global markets. In order to overcome these challenges, industrial organizations will need new capabilities to manage the value chain in their products in a flexible and lean way.

Within this national economic and industrial momentum, concepts of Total Quality Management, Industry 4.0 and Sustainability, are considered of major importance to the achievement of the goals of the strategic program that articulate the Vision 2030 (NIDLP, 2022).

The present paper attempts to review and discuss the interaction between the three paradigms that drive the modern businesses, Total Quality Management (TQM), Industry 4.0 and sustainability performance (Figure 1), and addresses future research prospects to be adapted in the Middle East and North Africa (MENA) region countries. The present research paper uses a literature review methodology to answer three research questions. Specifically:

1. What is the state-of-the-art literature regarding total quality management, Industry 4.0, and sustainability?

2. In what way, according to the recent literature, could Industry 4.0 associated with total quality management improve the sustainability performance in industrial organizations?

3. To what extent this study can benefit manufacturing organizations in the MENA region, which is witnessing a drastic economic and social change?

Figure 1 – Research Focus of the Present Paper

The present research can be considered as exploratory research since it seeks to explore the causal relationship between Industry 4.0 and sustainability performance as well as Total Quality Management and Industry 4.0, and the joint impact of Industry 4.0 technologies and Total Quality Management on the sustainability performance in industrial organizations. Additionally, the present research tried to ascertain whether the literature includes the Total Quality Management impact on Industry 4.0 technologies adoption and achieving sustainable performance in manufacturing. This study offers new insights into the impact of Industry 4.0 technologies and Total Quality Management on the industrial organizations' environmental, economic, and social performance. In addition, it highlights managerial implications and theoretical contributions to the industries .

It is important to note here, that the present paper is a preliminary study to explore from a literature review perspective, the relationship between the three paradigms (TQM, I4.0 and Sustainability). This research will constitute the basis for constructing a theoretical framework to be tested in manufacturing settings in Saudi Arabia.

RESEARCH METODOLOGHY

The research methodology is based on a review of the actual literature on the topic. Research on digital transformation (industry 4.0) technologies' impact on total quality management to ensure sustainability has gained a lot of research interest in both academic and professional experts (Baran, & Korkusuz, 2022). Most importantly, it is not sufficiently connected, especially concerning the fourth industrial revolution and the field of business sustainability, which has been noted as a source of great interest by organizations. This study examines, summarizes, and combines many concepts and cases from the literature to address this fact, based on linking total quality management to the fourth industry technologies.

This research is designed with the dual objective of: (1) determining the importance of the industry 4.0 technologies for total quality management and sustainability, and (2) Understand the research gaps based on what was previously discussed in related research and ways to develop future research on the impact of Total Quality Management and Industry 4.0 on sustainability.

The following review is not planned to be an exhaustive examination of the unique relationships in the middle of different technologies and their influence on total quality management. However, it seeks to identify the ecosystem that integrates new technologies and total quality management for achieving sustainability, based on the published literature.

To assume our review of the previous literature to find an answer to our questions, we analyzed papers published by academic and professional authors. The first check of the sources included Scopus and Web of Science databases to identify high-impact scientific publications using citation rates. While these sources have ensured their total quality and effectiveness for the research sector, they have also excluded some papers from the scope of this research, especially those that refer to very outdated reviews. As a result, the second phase focused on recent publications with emerging but common-impact research learnings and academic perspectives. An additional literature search was conducted using Google Scholar, one of the included databases (Xie, & Miyazaki, 2013).

A literature review was conducted to find studies discussing Total quality management philosophy and its impact in this study. The keywords used in the search strategy were "Total Quality Management," "Industry 4.0," and "Sustainability". These." keywords were ideal for collecting reliable and credible studies from the data as mentioned earlier base sources (Table 1). Boolean operators for instances AND. OR and NOT were utilized when relating these terms and explaining the connection between the search strategy terms. These Boolean operators are often used to broaden or narrow the set of studies reflected during the search. They play a crucial role in arriving at the most reliable studies that conform to the research questions and objectives. The "AND" is usually utilized when narrowing the search, while "OR" is crucial when broadening the scope of the study. On the other hand, "NOT" is used when trying to eliminate some terms from the search results (Bramer et al., 2018).

Table 1 – Search Sequence Definition

Theme		Search Terms
"Total Quality Management"	AND	"Total Quality Management" OR "TQM" OR "Quality Management" OR "Quality 4.0" OR "Quality"
"Industry 4.0"	-	"Industry 4.0" OR "I4.0"
"Sustainability"	AND	"Sustainability" OR "Sustainable Development"

The first group of articles was obtained by conducting a search for the terms combination indicated in table 1. Additionally, research was conducted on the references of other sources to broaden the scope of the search. It was determined to include all sources that were clearly dedicated to Total Quality Management as well as those that were only loosely connected, particularly those relating to Industry 4.0 and/or sustainability. As a result, sources with at least one of the defined word/term search string combinations in the title, abstract, or keywords were examined, as shown in Table 1. Additionally, sources that lacked the whole text for evaluation were not written in the English language or were not published between 2015 and the end of 2021 were removed, with an emphasis on the most recent with a very high citation rate.

Overall, this assessment was based on books, academic articles, and conferences on engineering and total quality management, industrial management, industrial revolution 4.0, and business sustainability. The decision was based on careful consideration of the total quality management of each study and its relevance to the identified gaps, as well as the strengthening of relevant opinions.

Initially, more than 100 sources were identified within the current search criteria in the selected databases. After removing the duplicates, about 80 references were retained for analysis. After the initial investigation, all sources with materially relevant content in the abstract or abstract were included in the review. This stage allowed for the final selection of 56 references, which were then analyzed. Figure 2 illustrates the research process and source selection criteria adopted by the researchers in the present paper.

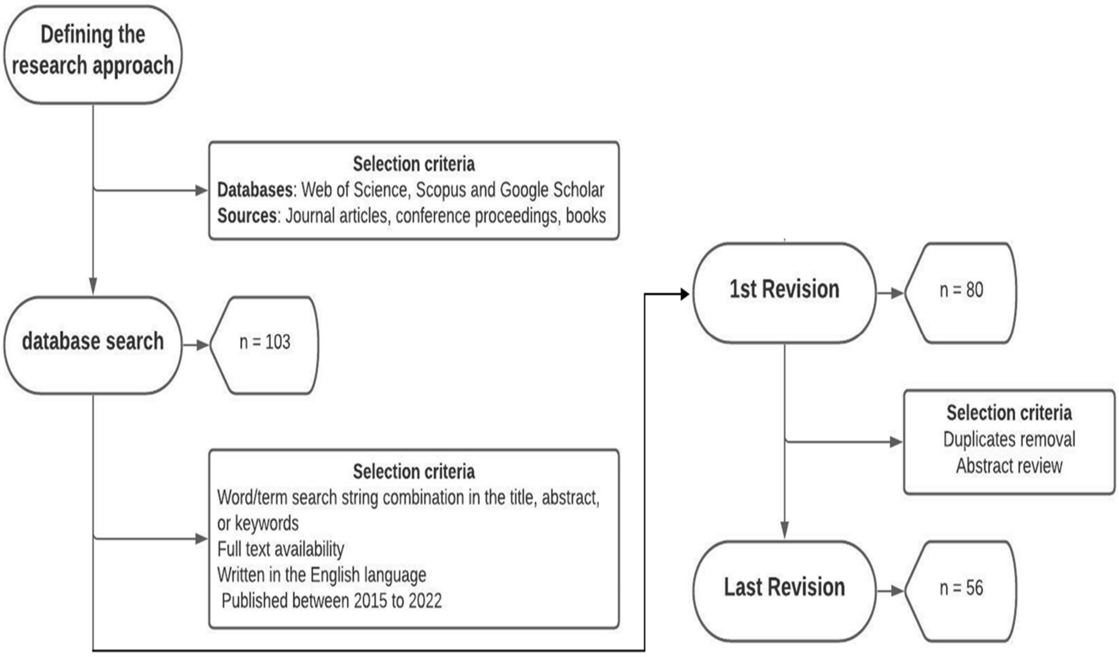

Figure 2 – Research process and article selection criteria.

The Critical Appraisal Skill Program (CASP) was utilized to evaluate the 56 studies' quality for review in this particular study (Burls, 2014). Every article and journal used was subjected to specific questions to test their quality for research, examine their findings, and confirm whether the selected studies conform to the research topic, objective, and questions under scrutiny. More so, the structure, year of publication, and the adopted methodology were crucial in testing the validity of the chosen materials. Furthermore, the CASP scrutinizes this specific study's aim, for instance, populations, findings, comparison, and the procedures utilized to achieve those objectives. Table 2 below summarizes the crucial review of the material utilized in this particular study.

Table 2 – Critical Appraisal Skill Programme (CASP)

Research Questions		
Validity Questions	**Result questions**	**Applicable questions**
1. What is the objective of the research? 2. Which method was utilized to assemble data? 3. What specific data was collected? 4. How was the evaluation done?	1. Does the outcome of the research reflect the research topic? 2. Are our research questions well answered? 3. Can the finding be utilized to interpret the research outcome? 4. Is the result credible and trustworthy? 5. Could there be publication bias?	1. How is the study designed to answer the research questions? 2. What is the significance of the study to the community?

A thematic analysis approach was mainly suitable for closely tracking the fifty-six studies' suitability (Clarke, et al., 2015). The approach is critical when analyzing a set of texts and essential themes. Thematic analysis was utilized to closely examines the studies to identify the common themes on the impact of TQM and I4.0 technologies on sustainability. The process involved carefully reading each chosen study to grasp better and fully comprehend the concepts presented in the paper. The thematic analysis approach simplified the process of keeping track of Mixed studies, qualitative and quantitative studies selected for the study. This facilitates generating new insights and concepts mainly related to industry 4.0 technologies' impact on total quality management to ensure sustainability performance in industrial organizations.

RESULTS AND DISCUSSION

Bibliometrics Analysis

Analyzing and categorizing the contributions published in the literature on a topic allows a better understanding of the current state of research, identifying the most relevant issues, and exploring current gaps and future research avenues (Kraus, et al., 2020). Since the case of introducing TQM in the Fourth Industrial Revolution with a focus on sustainability is a recent but already discussed issue at times, we chose bibliometric analysis as a starting point for this work.

Precisely because of the modern and growing nature of the topic, the first point of this analysis focused on the distribution of scholarly publications over time, see figure 3. It has been on the rise since then. Hence, we conclude that there is interest by researchers. This is a good starting point for researching this rapidly growing topic.

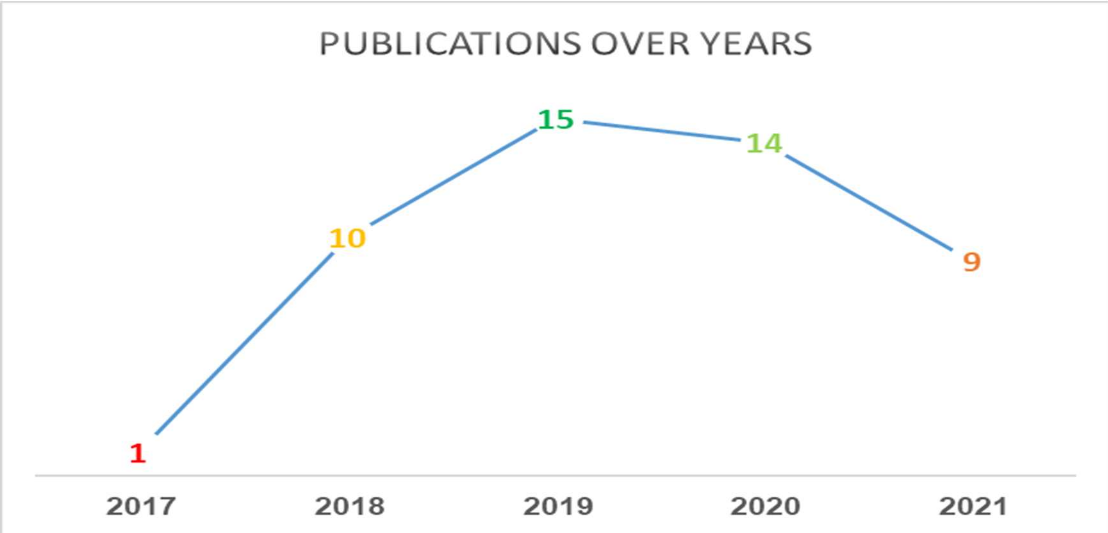

Figure 3 – Research publications over the years.

In another context, the geographical distribution of the participating researchers who published the works related and used in the literature study in this research was addressed. We can say that most of the scientific publications were issued by Brazil, followed by the United States of America, China, India, and many other developed countries, and accordingly, we can say clearly that the issue is being dealt with in a global way. Also, it was found that scares number of publication dealt with the MENA region in general and with the Saudi Arabia in particular.

Finally, the keywords used in the references in our research were evaluated and represented in this part. The most frequently used words were "industry 4", "total quality management", "quality", and "sustainability". The term "industry 4" was the most common and used due to the novelty and strength of the subject and its close connection with all other matters. They include but are not limited to topics such as technology, business management, and an approach that emphasizes quality. When "quality" is linked to "sustainability", it emphasizes many essential aspects of digital transformation in the fourth industrial revolution, focusing on management systems or as it is called total quality management. A clear link between technology and "quality" can also be seen, highlighting how modern technologies feature and integrity of I4.0. Finally, "technology" is closely related to sustainability. It is also worth noting the use of keywords associated with literature reviews, with this method of research being the most popular, likely due to the novelty of the topic.

For more validation of the current research aim, a Google Trends shows interest in terms of the region of interest over time for any keyword searched for in the Google search engine (Figure 4). In an academic sense, we can say that the level of interest in the topics studied over time is represented by the rate of interest in the search term compared to the highest point in the graph for the specified region and period (Choi, & Varian, 2012). In our case, the specified period is (2004–2021). A value of "100" represents the high popularity of the search term, a matter of "50" means half of the phrase's favor, and a value of "0" means there is not enough data for that search term. To check the global potential in one aspect, an examination of interest over time was sufficient to establish what people were searching for in the given years, given the three terms studied in this research (total quality management, industry 4.0, and sustainability). Using the above, it was noted that the search for the first term (total quality management) and the second term (sustainability) was very strong at the beginning of the study (2004), and in the same context, the third term (Industry 4.0) was completely absent. With the emergence of the new term in 2015, known as the Fourth Industrial Revolution, the decline of the other two periods began to be within 75%, and the search for the new term increased.

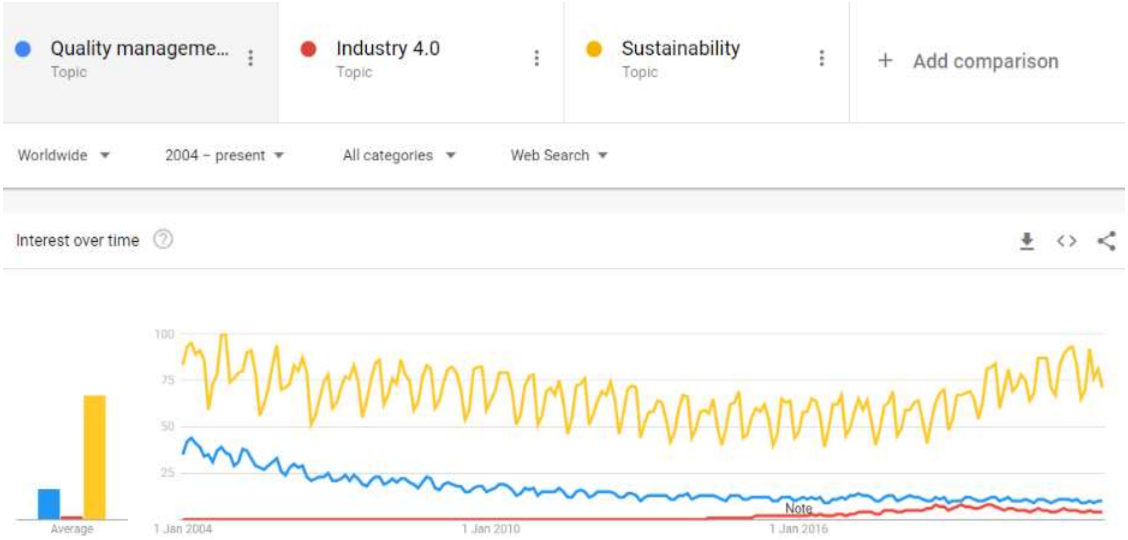

Figure 4 – Google search on the three terms of the research area.

In any case, we note that there has been a relationship in the past three years where the trend of research has remained stable, and tends to rise, which confirms that the three elements will be related to each other. Moreover, this increasing trend in the number of searches has continued, and in the opinion of the researcher, this situation will occur over the next few years. The researcher also noted that there is a lot of updated research on the topics of the Fourth Industrial Revolution, which is increasing significantly compared to research on TQM. Therefore, the importance of the study comes from filling this research gap. It was also noted that the last state-of-the-art research on TQM was nearly ten years ago. Proceeding from this matter and emphasizing the importance of total quality management, the current study was started to close the research gap.

Literature Review Aspect

This section offers a detailed overview of the existing literature associated with total quality management within the fourth industrial revolution. Few studies have been chosen for review to ensure that the whole process of narrative review remains focused on the topic of interest. More so, the objective and the scope of the study were taken into consideration was considered when choosing the studies to review. The review was centered on the impact of TQM on business, in particular sustainability and performance of the business firms. The research also focused on the challenges firms encountered while implementing TQM economic and innovative models.

The literature on digital transformation typically reveals a paternalistic attitude toward total quality management, with a shortage of and inventiveness within the industry. In our review, we endeavored to include all papers that may be used to disprove this viewpoint. This paper does this by summarizing the alleged advantages of the association among industry 4.0 technology and total quality management (Varela et al., 2019). It presents a holistic picture of how this link may be researched further to improve organizational effectiveness. The purpose of this article is to highlight the pragmatic value of modern technology in the interest of more outstanding total quality management. Three major themes emerged from a survey of the literature. It is divided into three categories: (a) Digital Total Quality Management, which is the application of Industry fourth technologies to Total Quality Management in particular, its methods, tools, and organizations, as well as the impact on sustainability; (b) Managing Total Quality Management of Digital Production systems and Services for better sustainability performance; and lastly, (c) Managing the Total Quality Management of Digital Development of Product and Manufacturing Procedures. Those pieces of information served as the foundation for the review of the literature (Aichouni, Kolsi and Aichouni, 2020; Fatimah et al., 2020).

Total Quality Management Philosophy

Total quality management (TQM) can be defined as a management approach that targets to achieve excellence in business through quality. It focuses on increasing customer satisfaction and delight through delivering high quality product and services, in addition to promoting employee involvement through teamwork, empowerment, and leadership (Sader, Husti and Daróczi, 2019). Digital Total quality management is described here as digital technology applied to total quality management, resulting in modifications to the organization's tools, procedures, and systems, both technological and human. Related research examines the difficulties that these TQM specialists confront in a progressively more linked and data-driven industrial context (Aquilani et al., 2017; Morocho-Cayamcela, Lee and Lim, 2019; Rafique et al., 2019). Analyzing and governing discrete activities becomes outmoded as systems grow more connected and networked. Some writers argue that statistical process control should be rethought, alleging that technology has displaced process control. The author claims that may regain its relevance if used as a managerial tool, focusing on system and organizational management rather than remote process control (Moktadir et al., 2018).

According to some authors, Industry 4.0 technologies and methodologies should be applied to establish data strategies to improve the enterprises' total quality management, process efficiency, and analysis. However, there is still a lack of integration between Quality management and Big Data, and it is necessary to analyses and address significant gaps to improve this reality (Sordan et al., 2020). Quality management must embrace big data, be compatible with evolving technologies, and be built so that predictive analytics and multivariate analysis are included (Albliwi, 2017). Utilizing event logs to gather data about their business processes, the authors examine the adoption of process techniques in Quality management-established process improvement projects, emphasizing the advantages of using process mining to collect data about their business processes. This has resulted in the development of a standard operating procedure to assist organizations in increasing the productivity and efficiency of their procedure improvement efforts. It enables data extraction from the event logs of numerous operations (Zairi, 2020). It results in a more accurate description of processes, products, and organizational systems (Zairi, 1991), and it may be used to improve total quality management, audits, compliance adherence, and risk management (Fettermann et al., 2018).

Additionally, it enables automatic process model discovery from intense incident data and compliance checking and bottleneck analysis (Nunhes and Oliveira, 2020). Consequently, process removal combines digitalization and data-science with total quality management systems. It holds for an organization's process-centric approach by providing crucial inputs to integrated management systems and facilitating more significant process optimization, compliance, and standardization (Fu et al., 2019). Similarly, collecting and maintaining data is critical to generating such value. Thus, the application of these information innovations must be accompanied by high-total quality management tools and processes, boosting their usability as administrative tools in the digital era (Barricelli, Casiraghi and Fogli, 2019).

There is an opportunity to investigate the human side of total quality management regarding its alignment with technology. Various scenarios are used to elicit varying degrees of engagement. Micro-level involvement focuses on risks, security, compliance, the configuration of total quality management systems, and the application of emerging industry 4.0 technologies. Macro-level attention is more concerned with the continual difficulties of improvement posed by human factors and technological advancement (Bano et al., 2018). The authors, on the other hand, highlight a significant study gap in their knowledge of how human factors impact the integration of overall quality management and technological advancements. As a result, this is consistent with a larger industry tendency (Bag et al., 2021).

Industry 4.0 Concept and Technologies

Competition for market share has pushed firms to develop their manufacturing procedures and practices by leveraging upcoming Industry 4.0 technology (Muhuri, Shukla and Abraham, 2019; Souza et al., 2021). The new production systems are smarter, more intelligent, adaptable, digital, and agile, and better equipped to deal with market volatility and adapt to the evolution of global markets. With the emergence of Industry 4.0 technologies such as cloud computing, big data analysis, robotic systems, and the Internet of Things, the global industrial industries have seen dramatic changes. Industry 4.0 technologies are crucial to manufacturing industries' sustainability performance, as they result in enhanced machinery, improved communication technology, shorter lead times, safer working environments, and increased product quality (Moktadir et al., 2018; Chiarini, 2020a).

The digital transformation accelerated the use of digital products, introducing new perspectives on total quality management. Incorporating Internet of Things (IoT) technology into these things is one example. The Internet of Things (IoT) gadgets are connected and capable of interacting with a centralized system (Manavalan and Jayakrishna, 2019). They add value to end-user goods by enabling continuous monitoring, problem detection, and diagnostics of these things. By integrating and validating a system's numerous aspects and components—its devices and sensors, gateways, and applications—IoT solutions offer higher levels of Total Quality Management Assurance (Liu and Zhang, 2020; Nižetić et al., 2020).

When new services and products can gather, generate, or utilize big data, combination becomes possible. Nonetheless, it is vital to appreciate the critical nature of the knowledge gathered while working with massive volumes of data (Gupta, Modgil and Gunasekaran, 2020; Bag, Gupta and Kumar, 2021). Value is created once the data is utilized to benefit the business (Jiang, Yin and Kaynak, 2018). This occurs only when the gathered data is digested and used to develop feasible solutions that benefit the company in terms of performance, product quality and sustainability (Malek and Desai, 2019; Nižetić et al., 2019; Fatimah et al., 2020).

As a result, in the context of digital transformation, data total quality management has become a critical component of total quality management. With newly connected items cooperating with vast amounts of data, integration is aided by forming information circles that enable new functionality based on system cooperation (Beard-Gunter, Ellis and Found, 2019). They argue for the seamless integration of a product's digital and "physical" components. Nevertheless, it is crucial to note that the conceptions of connectivity, digitization, and analytics go further than the primary use of platforms and technological tools (Nguyen, Phan and Matsui, 2018) and should instead focus on adapting to them to boost efficiency and benefit creation meant for consumers (Beard-Gunter, Ellis and Found, 2019; Bag, Gupta and Kumar, 2021; Souza et al., 2021). Additionally, machine learning and artificial intelligence have promise in the context of data-driven and digital commodities. Machine learning and artificial intelligence may be utilized to integrate total quality management reliability and control analysis, resulting in predictive maintenance, and a reduction in customer complaints. Nonetheless, substantial worries persist over the safety of machine learning, a subject that will considerably impact the total quality management of these items, processes, and systems. The same is true of bias directed against specific groupings or communities (Bano et al., 2018).

The Sustainability Concept

Sustainable development is a new, accelerating, and emerging trend that is important to all humanity. We are enjoying a higher quality of life, driven by rapid economic growth. But at the same time, we need to deal with serious environmental degradation (pollution, global warming, etc.) and social problems (poverty, diseases, inequity, etc.). Sustainability is the key imperative in modern life. Great efforts have been made by international organizations (UN) and national governments to ensure a better quality of life and to protect the environment through laws, action plans, and initiatives. These regulations put more emphasis on manufacturing and industries' adopting sustainability concepts through the whole product life cycle. Sustainability assessments have been used to analyses potential environmental impacts associated with all stages of product life cycle management, from raw materials extraction to the use of the product by the end user and consumer and its disposal after use (Nguyen, Phan and Matsui, 2018).

Sustainability is described as "meeting the needs of the present generation without compromising the ability of future generations to meet their own needs." Sustainability is concerned with the "three pillars of sustainability," which includes social, economic, and environmental aspects. Social sustainability entails a dedication to ensuring that everyone has access to healthcare, education, food, safe drinking water, and adequate housing. Additionally, it implies the maintenance of a stable and peaceful global community of nations. Economic sustainability entails anticipating economic downturns, investing for the long term, regulating the financial industry, and paying down the national debt. Climate change, global warming, human coexistence, ocean acidification, ecological collapse, air pollution, and ozone depletion all contribute to environmental sustainability. Renewable energy, endangered species protection, emissions reduction, and recycling are all solutions in this realm. The world can make a significant transition to an exciting and prosperous future by committing to sustainability across all industries and activities (Tortorella, Giglio and van Dun, 2019).

Substantial research efforts have been devoted to understanding the causal relationship between management strategies such as TQM, LSS, Process Improvement and sustainability in one hand (Kouhizadeh, Saberi and Sarkis, 2021). In another hand the effect of Industry 4.0 technologies on sustainability has been studied in many organizational contexts (Iyer, Saranga and Seshadri, 2013).

DISCUSSION ON THE RELATIONSHIP BETWEEN TQM, INDUSTRY 4.0, AND SUSTAINABILITY AND ITS IMPLEMENTATION IN INDUSTRIAL ORGANIZATIONS

The emerging focus on the globalization of businesses, their competitive nature, and the sustainability regulations and imperatives, let to a substantial research effort to investigate the conceptual relationships between Total Quality Management, Industry 4.0 and sustainability all over the world. The three concepts have been extensively explored as combination of pairs.

The relationship between additive manufacturing (AM), as one of the main technologies belonging to Industry 4.0, and total quality management was considered in values studies. Product features and usability can benefit from AM; it contains advantages such as prototyping faster design, and development (Varela et al., 2019), a greater degree of customization, and more personal engagement with consumers (Malek and Desai, 2019). AM allows improved total quality management and cost reductions by lowering tooling costs, cutting the time between design and manufacturing, and lowering the cost of rejected or reworked parts by letting the costumer approve the final design. This reality results in future empowerment and amplification of the customer's voice, culminating in a truly unique and individualized collaborative and co-creative experience (Malek and Desai, 2019).

Digital transformation provides more automation and strengthens total quality management control resources. The same important are in charge of optimizing processes and integrating processes, systems, and organizational domains (Nunhes and Oliveira, 2020). Additionally, it aids in involving the consumer in the development process and design, improving the customer satisfaction, and his experience.

The current review reveals the undeniable value the industry 4.0 technologies add to an organization's total quality management. Increased integration, intelligence and connectivity are among these benefits. Numerous new technologies enable and promote enterprise-wide integration and connectivity, enabling various operational elements and systems on the way to collaborate more efficiently. This enhances information distribution, total quality management, and efficiency while decreasing risk and hesitation and cutting production costs.

In table 3 we present a summary of research papers that dealt with the conceptual relationships between Total Quality Management, Industry 4.0 and sustainability. We include all related quality management approaches and systems with TQM such as Lean Six Sigma (LSS), organizational excellence models and Quality Management Systems (ISO 9001). The table shows that there is a research gap in combining the three emerging management concepts (Total Quality Management; Industry 4.0 and Sustainability) within the same study. From this table it can be clearly shown that the studies that investigated the causal relationship of the three concepts are very limited across the globe, and indeed very scarce and limited in the case of the MENA region in general and in Saudi Arabia in particular.

The context of the study represented by the Saudi industrial organizations would stress on this research gap further. So, it is believed that future research effort would be directed towards this area of research. This will contribute to the better understand the interaction between the three concepts within the Saudi industrial context driven since 2019 by the National Industrial Development and Logistics Program, one of the Saudi Vision 2030 programs. This is considered as the future direction of implementing the research study.

Table 3 – Mapping of Research Papers on TQM, I4.0 and Sustainability (Elaborated by the Researchers)

Researcher	Year	TQM	Other QMS	Industry 4.0	Sustainability	Country of Study
Sader et al.	2019	√		√		Hungary
Kouhizadeh	2021			√	√	US
Chiarini	2020	√		√		Italy
Varela et al.	2019		√	√	√	Portugal
de Souza et al.	2021	√			√	Brazil
Ghaithan et al.	2021		√	√		Saudi Arabia
Tsvetkova	2017			√	√	Bulgaria
Fatimah et al.	2020			√	√	Indonesia
Al Bliwi	2017		√			Saudi Arabia
Gunter et al.	2019	√		√		France
Nguyen, et al.	2018	√			√	Vietnam
Tortorella	2019		√	√		

CONCLUSION AND DIRECTION FOR FUTURE RESEARCH

The present research is built on the idea that study and coordination are absent from the technological components of digital transformation and total quality management, especially when we talk about the term sustainability (Nguyen, Phan and Matsui, 2018; Stamenkov and Dika, 2019). Faced with these facts, this research has reviewed the academic literature to discover many applied illustrations of how Total Quality Management (TQM) can be affected by using new technology to ensure sustainability, especially in its three criteria. As a consequence, an inclusive understanding of the relationship between TQM and technology that enables digital transformation has been obtained, which means we are on the path to achieving sustainability (Varela et al., 2019). First of all, it has been shown that despite its prevalence in the literature, some publications have previously examined the impact of technology on TQM in the context of digital transformation (Macchi et al., 2018; Barricelli, Casiraghi and Fogli, 2019). In addition, this research has resulted in the classification and consolidation of the reviewed research into three main categories: (a) Total Quality Management, which studies the application of industry 4.0 technologies to Total Quality Management itself, including its methods, and systems, with some focus on sustainability. (b) Implications for managing TQM in industry 4.0 products and services such as data-driven and characterized by increased connectivity. (c) Implications of TQM in the physical products and services.

To summaries the findings of the present study, experts refer to "Industry 4.0" as the Fourth Industrial Revolution. The term reflects a drive toward manufacturing digitalization, which experts and academics believe would result in considerable increases in efficiency, prices, and profitability in the shortest amount of time possible, as some have described it as being less than a few years. However, the issue of what is necessary to accomplish digital transformation and how it will contribute to enhance total quality management initiatives towards achieving sustainability at the long term will remain of primary importance.

From the literature review performed here, three main conclusions can be extracted. These are:

- Total Quality Management maintains a certain influence on organizational performance including the sustainability dimension.

- Adapting the Total Quality Management to the technologies of I4.0 results is an ecosystem that supports the integration between technology, quality and people in the industrial context.
- Industry 4.0 has a positive mediating effect on performance excellence including the sustainability dimension.

Finally, it can be said that the analysis allowed the researchers to check the general understanding of the research subject, including papers that dealt with the conceptual relationships between Total Quality Management, Industry 4.0 and sustainability. The literature analysis shows a research gap in combining the three emerging management concepts (Total Quality Management; Industry 4.0 and Sustainability) within the same study.

So, it is believed that this research topic would contribute to a better understanding of the interaction between the three concepts within the conceptual context. It targets to shed light on Industry 4.0 implications on total quality management practices and sustainability, emphasizing the rewards, the difficulties, and the tools that manufacturing organizations would require to succeed in achieving sustainability performance. Such a conceptual model would represent a good research topic to be validated in the MENA region context.

Given the exploratory nature of the present research, future prospects would be building a conceptual theoretical model that integrates the three concepts (TQM, I4.0 and Sustainability), and testing and investigating its validity with an empirical study within the Saudi industrial organizations. The results from such a future study would guide Saudi industrial organizations to adopt the concepts of TQM and Industry 4.0 for sustainability performance. These concepts constitute the foundations of the National Industrial Development and Logistics Program, one of the Saudi Vision 2030 programs.

LIMITATION OF THE STUDY

Using a literature review approach in a study in emerging fields of research, can sometimes led to research bias. Some important research papers may have been missed.

The time frame of the analyzed literature (2004-2021) may be considered short. This might interfere with the research outcomes.

REFERENCES

Aichouni, A.B.E., Kolsi, L. and Aichouni, M. (2020) "The Engineering Students Innovation Club Project for Human Capital Development in the areas of Industry 4.0 – From the Design to Implementation," in 2020 Industrial & Systems Engineering Conference (ISEC). IEEE, pp. 1–4. doi:10.1109/ISEC49495.2020.9229924.

Aquilani, B. et al. (2017) "A systematic literature review on total quality management critical success factors and the identification of new avenues of research," The TQM Journal, 29(1), pp. 184–213. doi:10.1108/TQM-01-2016-0003.

Bag, S. et al. (2021) "Role of institutional pressures and resources in the adoption of big data analytics powered artificial intelligence, sustainable manufacturing practices and circular economy capabilities," Technological Forecasting and Social Change, 163, p. 120420. doi:10.1016/j.techfore.2020.120420.

Bag, S., Gupta, S. and Kumar, S. (2021) "Industry 4.0 adoption and 10R advance manufacturing capabilities for sustainable development," International Journal of Production Economics, 231, p. 107844. doi:10.1016/j.ijpe.2020.107844.

Bano, S. et al. (2018) "Identifying the impacts of human capital on carbon emissions in Pakistan," Journal of Cleaner Production, 183, pp. 1082–1092. doi:10.1016/j.jclepro.2018.02.008.

Baran, E., & Korkusuz Polat, T. (2022). Classification of Industry 4.0 for Total Quality Management: A Review. Sustainability, 14(6), 3329.

Barricelli, B.R., Casiraghi, E. and Fogli, D. (2019) "A Survey on Digital Twin: Definitions, Characteristics, Applications, and Design Implications," IEEE Access, 7, pp. 167653–167671. doi:10.1109/ACCESS.2019.2953499.

Beard-Gunter, A., Ellis, D.G. and Found, P.A. (2019) "TQM, games design and the implications of integration in Industry 4.0 systems," International Journal of Quality and Service Sciences, 11(2), pp. 235–247. doi:10.1108/IJQSS-09-2018-0084.

Bramer, W. M., de Jonge, G. B., Rethlefsen, M. L., Mast, F., & Kleijnen, J. (2018). A systematic approach to searching: an efficient and complete method to develop literature searches. Journal of the Medical Library Association: JMLA, 106(4), 531.

Burls, A. (2014). What is critical appraisal?, Hayward Medical Communications.

Chiarini, A. (2020a) "Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research," The TQM Journal, 32(4), pp. 603–616. doi:10.1108/TQM-04-2020-0082.

Chiarini, A. (2020b) “Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research,” The TQM Journal, 32(4), pp. 603–616. doi:10.1108/TQM-04-2020-0082.

Clarke, V., Braun, V., & Hayfield, N. (2015). Thematic analysis. Qualitative psychology: A practical guide to research methods, 222, 248.

Choi, H., & Varian, H. (2012). Predicting the present with Google Trends. Economic record, 88, 2-9.

Dalenogare, L.S. et al. (2018) “The expected contribution of Industry 4.0 technologies for industrial performance,” International Journal of Production Economics, 204, pp. 383–394. doi:10.1016/j.ijpe.2018.08.019.

de Oliveira, O. J., da Silva, F. F., Juliani, F., Barbosa, L. C. F. M., & Nunhes, T. V. (2019). Bibliometric method for mapping the state-of-the-art and identifying research gaps and trends in literature: an essential instrument to support the development of scientific projects. In Scientometrics recent advances. IntechOpen.

Fatimah, Y.A. et al. (2020) “Industry 4.0 based sustainable circular economy approach for smart waste management system to achieve sustainable development goals: A case study of Indonesia,” Journal of Cleaner Production, 269, p. 122263. doi:10.1016/j.jclepro.2020.122263.

Fettermann, D.C. et al. (2018) “How does Industry 4.0 contribute to operations management?,” Journal of Industrial and Production Engineering, 35(4), pp. 255–268. doi:10.1080/21681015.2018.1462863.

Fu, Y. et al. (2019) “Stochastic multi-objective modelling and optimization of an energy-conscious distributed permutation flow shop scheduling problem with the total tardiness constraint,” Journal of Cleaner Production, 226, pp. 515–525. doi:10.1016/j.jclepro.2019.04.046.

Gupta, S., Modgil, S. and Gunasekaran, A. (2020) “Big data in lean six sigma: a review and further research directions,” International Journal of Production Research, 58(3), pp. 947–969. doi:10.1080/00207543.2019.1598599.

Iyer, A., Saranga, H. and Seshadri, S. (2013) “Effect of Quality Management Systems and Total Quality Management on Productivity Before and After: Empirical Evidence from the Indian Auto Component Industry,” Production and Operations Management, 22(2), pp. 283–301. doi:10.1111/poms.12000.

Jiang, Y., Yin, S. and Kaynak, O. (2018) “Data-Driven Monitoring and Safety Control of Industrial Cyber-Physical Systems: Basics and Beyond,” IEEE Access, 6, pp. 47374–47384. doi:10.1109/ACCESS.2018.2866403.

Kraus, S., Breier, M., & Dasí-Rodríguez, S. (2020). The art of crafting a systematic literature review in entrepreneurship research. International Entrepreneurship and Management Journal, 16(3), 1023-1042.

Kouhizadeh, M., Saberi, S. and Sarkis, J. (2021) “Blockchain technology and the sustainable supply chain: Theoretically exploring adoption barriers,” International Journal of Production Economics, 231, p. 107831. doi:10.1016/j.ijpe.2020.107831.

Kush, P. et al. (2021) “Systematic literature review of quality maturity matrix,” Total Quality Management & Business Excellence, 32(3–4), pp. 289–297. doi:10.1080/14783363.2018.1552130.

Liu, X. and Zhang, X. (2020) “NOMA-Based Resource Allocation for Cluster-Based Cognitive Industrial Internet of Things,” IEEE Transactions on Industrial Informatics, 16(8), pp. 5379–5388. doi:10.1109/TII.2019.2947435.

Macchi, M. et al. (2018) “Exploring the role of Digital Twin for Asset Lifecycle Management,” IFAC-PapersOnLine, 51(11), pp. 790–795. doi:10.1016/j.ifacol.2018.08.415.

Malek, J. and Desai, T.N. (2019) “Prioritization of sustainable manufacturing barriers using Best Worst Method,” Journal of Cleaner Production, 226, pp. 589–600. doi:10.1016/j.jclepro.2019.04.056.

Manavalan, E. and Jayakrishna, K. (2019) “A review of Internet of Things (IoT) embedded sustainable supply chain for industry 4.0 requirements,” Computers & Industrial Engineering, 127, pp. 925–953. doi:10.1016/j.cie.2018.11.030.

Moktadir, Md.A. et al. (2018) “Assessing challenges for implementing Industry 4.0: Implications for process safety and environmental protection,” Process Safety and Environmental Protection, 117, pp. 730–741. doi:10.1016/j.psep.2018.04.020.

Morocho-Cayamcela, M.E., Lee, H. and Lim, W. (2019) “Machine Learning for 5G/B5G Mobile and Wireless Communications: Potential, Limitations, and Future Directions,” IEEE Access, 7, pp. 137184–137206. doi:10.1109/ACCESS.2019.2942390.

Muhuri, P.K., Shukla, A.K. and Abraham, A. (2019) “Industry 4.0: A bibliometric analysis and detailed overview,” Engineering Applications of Artificial Intelligence, 78, pp. 218–235. doi:10.1016/j.engappai.2018.11.007.

Nguyen, M., Phan, A. and Matsui, Y. (2018) “Contribution of Quality Management Practices to Sustainability Performance of Vietnamese Firms,” Sustainability, 10(2), p. 375. doi:10.3390/su10020375.

Nicoletti Junior, A. and Oliveira, M.C. de (2019) “The impact of the implementation of the quality management system on organisational performance: an action research in a Brazilian brewing manufacture,” Total Quality Management & Business Excellence, 30(11–12), pp. 1411–1427. doi:10.1080/14783363.2017.1417735.

Nižetić, S. et al. (2019) “Smart technologies for promotion of energy efficiency, utilization of sustainable resources and waste management,” Journal of Cleaner Production, 231, pp. 565–591. doi:10.1016/j.jclepro.2019.04.397.

Nižetić, S. et al. (2020) “Internet of Things (IoT): Opportunities, issues and challenges towards a smart and sustainable future,” Journal of Cleaner Production, 274, p. 122877. doi:10.1016/j.jclepro.2020.122877.

Nunhes, T.V. and Oliveira, O.J. (2020) “Analysis of Integrated Management Systems research: identifying core themes and trends for future studies,” Total Quality Management & Business Excellence, 31(11–12), pp. 1243–1265. doi:10.1080/14783363.2018.1471981.

Oztemel, E. and Gursev, S. (2020) “Literature review of Industry 4.0 and related technologies,” Journal of Intelligent Manufacturing, 31(1), pp. 127–182. doi:10.1007/s10845-018-1433-8.

Permana, A., Purba, H.H. and Rizkiyah, N.D. (2021) “A systematic literature review of Total Quality Management (TQM) implementation in the organization,” International Journal of Production Management and Engineering, 9(1), p. 25. doi:10.4995/ijpme.2021.13765.

Powell, T.C. (1995) “Total quality management as competitive advantage: A review and empirical study,” Strategic Management Journal, 16(1), pp. 15–37. doi:10.1002/smj.4250160105.

Rafique, M.Z. et al. (2019) “A systematic review of lean implementation approaches: a proposed technology combined lean implementation framework,” Total Quality Management & Business Excellence, 30(3–4), pp. 386–421. doi:10.1080/14783363.2017.1308818.

Sader, S., Husti, I. and Daróczi, M. (2019) “Industry 4.0 as a Key Enabler toward Successful Implementation of Total Quality Management Practices,” Periodica Polytechnica Social and Management Sciences, 27(2), pp. 131–140. doi:10.3311/PPso.12675.

Saudi Vision 2030, The National Industrial Development and Logistics Program https://www.vision2030.gov.sa/v2030/vrps/nidlp/

Sordan, J.E. et al. (2020) “Lean Six Sigma in manufacturing process: a bibliometric study and research agenda,” The TQM Journal, 32(3), pp. 381–399. doi:10.1108/TQM-08-2019-0207.

de Sousa Jabbour, A.B.L. et al. (2018) “When titans meet – Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors,” Technological Forecasting and Social Change, 132, pp. 18–25. doi:10.1016/j.techfore.2018.01.017.

Souza, F.F. de et al. (2021) “Total quality management 4.0: adapting quality management to Industry 4.0,” The TQM Journal, ahead-of-print(ahead-of-print). doi:10.1108/TQM-10-2020-0238.

Stamenkov, G. and Dika, Z. (2019) “Quo vadis, (e-)service quality? Towards a sustainability paradigm,” Total Quality Management & Business Excellence, 30(7–8), pp. 792–807. doi:10.1080/14783363.2017.1338521.

Tortorella, G.L., Giglio, R. and van Dun, D.H. (2019) "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement," International Journal of Operations & Production Management, 39(6/7/8), pp. 860–886. doi:10.1108/IJOPM-01-2019-0005.

Varela, L. et al. (2019) "Evaluation of the Relation between Lean Manufacturing, Industry 4.0, and Sustainability," Sustainability, 11(5), p. 1439. doi:10.3390/su11051439.

Xie, Z., & Miyazaki, K. (2013). Evaluating the effectiveness of keyword search strategy for patent identification. World Patent Information, 35(1), 20-30.

Zairi Mohamed, (2020), Total Quality Management: Contributions to Theory and Application; ISBN:10-1674379064, Independently Published, Available on Amazon.com.

Zairi, Mohamed, (1991), Total Quality Management for Engineers, Woodhead Publishing Limited, Cambridge, UK.

Statistical Process Control techniques to monitor quality determinants in digital Voice-of-Customer

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STRUCTURED ABSTRACT

Purpose - Digital Voice-of-Customer (digital VoC) primarily consists of textual feedback posted by users of products or services on the web. Digital VoC may represent a valuable source of information for quality management, and its promising potential is also receiving a lot of attention in the new Quality 4.0 framework. However, manufacturers and service providers still lack operative approaches to fully exploit the value of digital VoC. This study tries to answer the following research question: *How Statistical Process Control (SPC) techniques can be used to monitor digital VoC over time*?

Design/methodology/approach - This article explores the applicability of SPC to support digital VoC analysis. Two types of control charts, for variables and attributes, were applied to a real case study concerning a product-service system (car-sharing).

Findings - SPC tools may represent an interesting alternative to traditional quality tracking approaches to analyze the evolution of quality determinants over time.

Originality/value – This study shows how Artificial intelligence algorithms and SPC tools may support product and service designers in implementing continuous improvement actions by analyzing digital VoC over time.

Keywords: Statistical Process Control, Control charts, Voice-of-Customer, Topic modelling, Quality 4.0

Paper type: Research paper

1. INTRODUCTION

The survival of any business in an increasingly competitive scenario is closely tied to having satisfied and loyal customers (Psarommatis et al., 2020). In this view, organisations need to monitor the performance of their products/services over time. To effectively manage quality, it is essential to understand which are the key influencing factors (Franceschini et al., 2009), also known as quality determinants, to allow organisations to measure, control, and improve the way customers perceive a product/service (Mukherjee, 2019).

Organisations employ quality tracking techniques to monitor the evolution of quality by directly auditing consumers (Kamsu-Foguem et al., 2013; Xu et al., 2021) and by analysing the so-called "Voice-of-Customer" (VoC) (Jach et al., 2021). Traditional quality tracking techniques collect VoC from interviews, questionnaires, or focus groups. The main limitations of these activities are that (i) they are expensive in terms of required time and resources, (ii) they can only reach a limited sample of customers, and (iii) they can be quite intrusive for the interviewed customers.

The digitalisation of consumption has enabled customers to release massive quantities of VoC on the web, i.e., digital VoC. Such data, also known as User-Generated Contents (UGC), primarily consists of customer reviews, i.e. unstructured textual records describing the customer's experience with a specific product or service (Elg et al., 2021; Mastrogiacomo et al., 2021). Many studies have already proven that digital VoC analysis can be of great value for quality management and design (Barravecchia et al., 2021; Barravecchia et al., 2020a, 2020b; Mastrogiacomo et al., 2020). One of the most effective techniques for analysing digital VoC is topic modelling, i.e. artificial intelligence algorithms that can extract latent topics discussed within collections of unstructured text documents. When applied to digital VoC collections, topic modelling algorithms allow the extraction of latent quality determinants of the product/service analysed (Mastrogiacomo et al., 2020). The output of topic modelling algorithms is rich in information and it can be of great value in the management and monitoring of quality.

To date, digital VoC analytics have not yet been used to explore the evolution of quality determinants. The current challenge is then to understand how to leverage on digital VoC analysis to monitor quality determinants over time. In this view, the objective of this study is to provide a preliminary analysis of how Statistical Process Control (SPC) may support digital VoC analysis. In detail, the study tries to answer the following research question: *How can Statistical Process Control (SPC) techniques be used to monitor digital VoC over time?*

The remainder of this paper is organised into three sections. Section 2 provides the conceptual background and the significant research that has been conducted on quality tracking and digital VoC. Section 3 describes two preliminary applications of SPC techniques for the analysis of digital VoC.

Finally, Section 4 summarises the main contributions of the work, its limitations, and possible future research directions.

2. CONCEPTUAL BACKGROUND

2.1. Customer Satisfaction

According to the international standard ISO/FDIS 10004 (2018), customer satisfaction is the customer perception of the degree to which expectations are met by a product (or service). There are multiple interpretations of the concept of Customer Satisfaction (CS) in the literature; however, all definitions share three common elements:

- consumer satisfaction is an emotional or cognitive response;
- the response relates to a particular focus (expectations, product, consumer experience, etc.);
- the response occurs at a particular time (after consumption, after choice, etc.).

CS is the resulting aggregate assessment of all latent dimensions characterising product or service quality (Matzler & Sauerwein, 2002). Tracking latent dimensions over time provides an insight into how and why customer satisfaction is changing.

2.2. Voice-of-Customer

To analyse customer satisfaction, it is crucial to take the "Voice-of-Customer" (VoC) into account (Aguwa et al., 2012, Lysenko-Ryba et al., 2022). By actively investigating VoC it is possible to anticipate customer future needs and better design new products (Aguwa et al., 2012). Product development can be positively influenced by data collected in post-sales, as evidenced by the systematic use of this data in many industries such as, for example, in the automotive sector (Szwejczewski et al., 2015). Through VoC analysis, it is possible to identify (Wang & Tseng, 2011):

- *Explicit requirements*: requirements that the customer states explicitly (for example: a customer explicitly states that wants a red car).
- *Implicit requirements*: requirements that the customer does not express explicitly, but wants or needs (for example, someone who buys a washing machine expects it to be able to wash clothes, but will not explicitly express this need. It is considered an intrinsic characteristic of the washing machine).
- *Latent requirements*: requirements that cannot be easily expressed by the customer. Meeting these requirements is critical to the success or failure of a product.

A variety of techniques are available to intercept and analyse VoC. Table 1 provides a summary of traditional ones.

Table 1 - Traditional techniques for VoC Analysis (Freeman & Radziwill, 2018).

Technique	Description
Survey	Surveys are a popular method for collecting easily quantifiable feedback. They use predefined questions in a variety of formats including fillable text-boxes or multiple choice. Researchers can conduct surveys easily in person, over the phone, through web forms, or video. Surveys are useful for assessing and monitoring customer preferences and satisfaction, as well as for evaluating the impact of changes to products or services.
Benchmarking	Benchmarking is a practice in which organisations study how other organisations satisfy their customers' needs. It is a means to study best practices and learn how to pinpoint weaknesses in processes and design workflows.
Gemba Visits	Gemba is a technique in which the researcher goes to the workplace to get direct information about what customers want and need. It can be an excellent technique for observing workers directly in their environment, which is particularly useful when customers and workers don't feel they have the freedom to complain openly
Focus group	Focus groups allow researchers to spend time with customers to solicit answers to specific questions or engage in wide-ranging brainstorming sessions. These events can be conducted in person or with collaborative technology
Metodo Delphi	The Delphi Method is an interviewing technique in which researchers present subject matter experts with multiple rounds of questionnaires. Respondents then deliberate during each round until they narrow down their responses and reach a consensus.
Warranty data	Collecting data during the servicing of warranty claims can provide valuable information about product failures and customer dissatisfaction, as well as how customers think the products fail to live up to their promised functionality.

2.3. Quality tracking

Companies implement many strategies to track the evolution of a product/service quality over time, identify anomalies or criticalities, and uncover potential areas for improvement. Three practical approaches are typically considered (Bandaru et al., 2015; Hallencreutz & Parmler, 2021):

- *post-purchase evaluation*: this approach is performed by asking a customer to evaluate a purchased product or service after its delivery or use (Kumar & Anjaly, 2017);
- *periodic quality survey*: this approach, which is generally based on the administration of questionnaires or structured interviews, provides snapshots of customer perceptions (Izogo & Ogba, 2015; Su & Hwang, 2020);
- *continuous monitoring of quality*: this approach involves the ongoing monitoring of quality characteristics over time (Chen et al., 2015; Gregorio & Cronemyr, 2011; McColl-Kennedy & Schneider, 2000).

2.4. Digital VoC analysis

Information released by users on the web comes in different forms (text, audio, photos, videos). They are primarily published on social networks, discussion forums, blogs, review aggregators, and e-commerce platforms. By their influence on determining the demand and sales of a product, digital VoC can be considered a new form of word-of-mouth, so that consumers often perceive it as more reliable than traditional promotional practices (Wang, 2015).

Digital VoC is mainly composed of unstructured textual UGC. Users of a product/service freely describe their experience without following standard patterns and without providing readily processable structured data. In addition, the digital VoC is often composed of a large number of records shared by the customers. Given these properties, digital tools are needed to automatically extract information from digital VoC. Text mining approaches, i.e., techniques for the automatic analysis of unstructured textual documents, are widely implemented to analyse digital VoC (Berry & Kogan, 2010; Carnerud, 2020). These techniques allow hidden relationships to be found within textual data (Berry & Kogan, 2010). One of the most widely used text mining techniques for analysing unstructured textual information is topic modelling. The term topic modelling refers to the family of statistical methodologies that allow the latent topics discussed within a collection of documents to be extracted (Blei, 2012). In other words, these algorithms do not require human coding or a preliminary classification of data, as they can "read" a collection of documents and automatically extract the most discussed topics. Each topic is distinguished by a set of keywords. Figure 1 represents the conceptual scheme of a topic modelling algorithm. Given an extensive collection of digital VoC records $\{1,2,3,\dots,J\}$, topic modelling algorithms deal with the following aspects (Blei et al., 2003):

- identifying a set of topics that describe the text corpus (i.e., the collection of digital VoC);
- associating a set of keywords to each topic ($topical\ content$: $TC_{w,d}$),
  where:
    - $w \in \{1,\dots,W\}$ are the keywords of the vocabulary related to the digital VoC collection;
    - W is the total number of words contained in the digital VoC vocabulary.
    - $d \in \{1,\dots,D\}$ are the topics identified by the topic modelling algorithm
    - D is the total number of identified topics
- defining a specific mixture of these topics for each digital record (*topical prevalence*: $TP_{j,d}$)
  where:
    - $j \in \{1,\dots,J\}$ are the analysed digital VoC records
    - J is the total number of analysed digital VoC records
    - $\sum_{d=1}^{D} TP_{j,d} = 1 \quad \forall j$

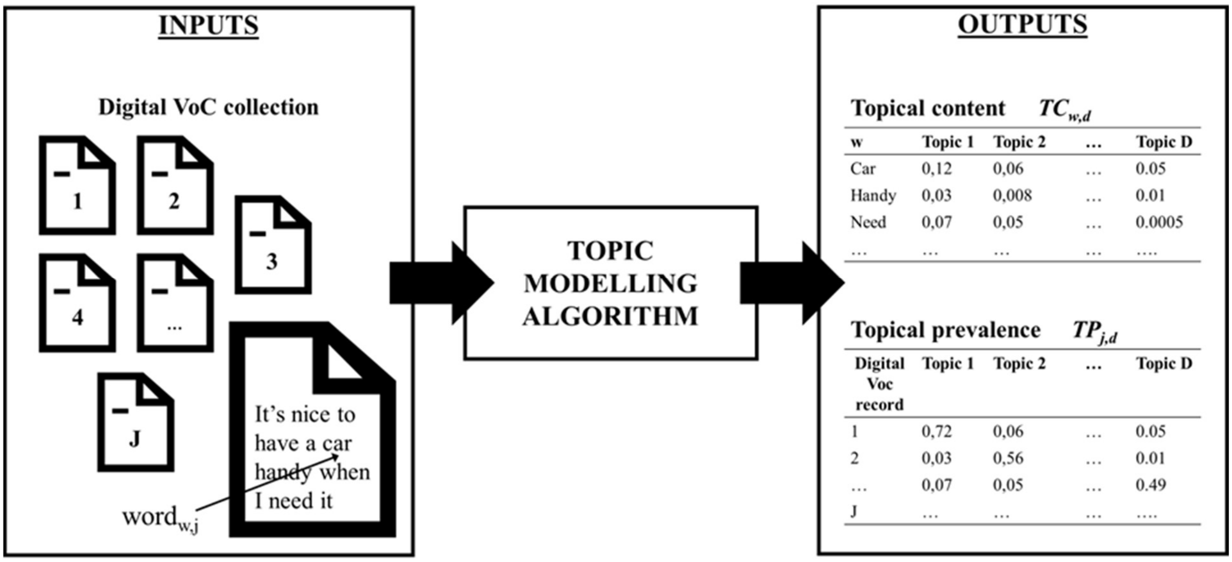

Figure 1 - Graphical representation of the functioning of topic modelling algorithms. The input consists of *J* textual documents (digital VoC records). The output consists of: $TC_{w,d}$ (Topical content matrix), i.e., the weights associated with each *w*-th keyword that characterises the *d*-th topic; $TP_{j,d}$ (Topical prevalence matrix), i.e., multinomial probability distribution that indicates the proportion of the *d*-th topic discussed within the *j*-th document.

2.5. Statistical Process Control and digital VoC Analysis

Collecting and analysing digital VoC records makes it possible to audit customer judgements more reliably than traditional techniques (Sweeney et al., 2008). The analysis of digital VoC can help organisations to overcome some of the limitations of conventional VoC collection techniques.

Topic modelling algorithms are able to extract the latent quality determinants (topics) of products or services, i.e., the feature that can positively or negatively influence the perceived quality (Barravecchia et al., 2020; Mastrogiacomo et al., 2021). It can be assumed that if a topic is discussed, then it is important for the customer, and therefore is critical to the perceived quality of the object under study.

The analysis of the outputs of topic modelling algorithms represents a possible source of information for assessing how consumer perceived quality varies over time. The variability in the "discussion level" (topical prevalence) of quality determinants may be investigated through tools typically employed in Statistical Process Control (SPC).

In the literature, there are few studies aimed at investigating how and to what extent the level of discussion of quality determinants varies over time. One of the first studies is dated 2008 (Lo, 2008). Lo applies a Support Vector Machine (SVM) algorithm to identify UGCs containing complaints by users of a website. After a preliminary classification of the complaints, their proportion is monitored through the use of control charts for attributes.

Ashton and Evangelopoulos (2012, 2014, 2015) proposed a model capable of exploring the evolution of different topics over time. More specifically, the authors identified the topics discussed in digital

VoC related to a large retail company using the Latent Semantic Analysis (LSA) algorithm and proposed an approach to monitor them over time. To keep track of changes in the proportions of the different quality factors, the authors used Exponential Moving Average Control Charts. Each control chart is specific to a single topic.

More recently, Liang and Wang (2019) proposed a monitoring methodology combining the analysis of the topics discussed in the digital VoC and the related sentiment expressed by customers. The proposed approach also tracks the distribution of customer sentiments, distinguishing positive from negative sentiments.

3. DIGITAL VOC CONTROL CHARTS

The analysis of the latent quality determinants in the digital VoC can identify anomalous behaviours. In general, two types of variability can be recognised:

- *natural variability*, which indicates the cumulative effect of a large number of small and uncontrollable causes;
- s*ystematic variability*, which indicates distortions in the process.

The identification of the *topical prevalence* of a latent determinant affected by a systematic variability can allow the detection of "out of control" situations of the analysed product/service. A control chart can signal the presence of a new source of variation, which can indicate an alteration in customer satisfaction due to specific assignable causes.

The application of control charts for the analysis of digital VoC needs to address the following aspects:

- *Which type of control chart to adopt*? Different types of variables can be considered, e.g., continuous variables (level of discussion of a quality determinant) or discrete variables (most discussed quality determinant in a digital VoC record).
- *How to manage quality determinants with trends*? It has been empirically observed that the quality determinants can exhibit different natural temporal trends in the topical prevalence: increasing, stationarity or decreasing trends (Barravecchia et al., 2020; Mastrogiacomo et al., 2021). The reasons behind these patterns may be different, including for example the evolution of customer needs or the learning of particular product/service aspects (Franceschini, 2002). Quality determinants characterised by specific temporal trends might require “focused” control charts capable of "following" these trends.
- *How to identify the sampling period*? The production rate of digital VoC by users may be subject to a variation over time. The choice of the sampling period (i.e., how often digital VoC records are grouped into a sample) can influence monitoring results. For example, a

long sampling period may mitigate the dynamicity of observations, but on the other hand, it may generate delays in the detection of potential out-of-controls.

- *How to manage the emergence of new quality determinants*? The number and type of quality determinants may change over time. The impact of the emergence or disappearance of some quality determinants needs to be investigated in detail.

In order to preliminary explore these issues, the following sub-sections propose an application of two different types of control charts to monitor a digital VoC database relating to a Product-Service System (car-sharing). The proposed applications concern the construction of the control charts.

3.1. Case study

The case study concerns the analysis of digital VoC regarding car-sharing services (Mastrogiacomo et al., 2021). The investigation is based on the application of the Structural Topic Model (STM) algorithm, which allows to include the metadata associated with the digital VoC for the definition of the topic model. The algorithm was implemented on the open-source R software using the STM package (M. E. Roberts et al., 2019). Analysed data are records retrieved in December 2019 from different databases: Yelp, Google, Trustpilot, Facebook, and Playstore. The time window of the analysis (i.e. the interval where the analysed samples are collected) is from January 2006 to December 2019 . Only English-language reviews were selected, with a total of almost 17,000 reviews from 22 car-sharing providers (Car2go, DriveNow, Maven, Zipcar, Goget), operating in 3 different countries (US, Canada, and UK).

Table 2 reports the keywords characterising the identified quality determinants and the corresponding assigned labels.

The comprehensive database of digital VoC was analysed in to identify quality determinants relevant to all the analysed car-sharing companies. Conversely, control charts developed in the following sections are related to a specific car-sharing provider.

Table 2 - Top keywords and related semantic labels of the quality determinants of car-sharing.

Quality determinant (d)	Keywords (w)	Quality determinant label
1	help, phone, call, person, office, answer, number	Customer service (physical office)
2	damage, report, accident, fault, member, enterprise, claim	Accident & damages management
3	sign, process, website, license, drive, driver, registration	Registration process
4	charge, fee, late, return, time, pay, hour	Charges & fees
5	park, lot, spot, find, ticket, street, space	Parking areas
6	app, work, update, book, map, reserve, time	App reliability
7	trip, end, time, make, actual, take, system	End trip issues
8	gas, dirty, rent, clean, tank, card, tire	Car condition
9	need, convenient, quick, recommend, awesome, clean, perfect	Convenience
10	hour, price, rate, cost, expense, mile, cheaper	Use rates
11	minute, reservation, walk, wait, home, time, away	Car proximity
12	car, available, location, vehicle, area, change, time	Car availability
13	use, time, now, far, user, review, star	Efficacy
14	city, year, insurance, member, gas, need, month	Sharing benefits
15	service, custom, issue, company, terrible, problem, experience	Customer service responsiveness
16	way, drive, little, take, get, town, bus	Intermodal transportation
17	time, start, location, turn, lock, pick, key	Car start-up issues
18	call, member, cancel, ask, rep, refund, manage	Customer service courtesy
19	account, card, email, credit, month, day, membership	Billing and membership
20	reservation, plan, time, need, book, cancel, advance	Car reservation

3.2. $\bar{x} - s$ control charts for car-sharing quality determinants

In this section, we present an application of $\bar{x} - s$ control charts for car-sharing quality determinants. The *topical prevalence* ($TP_{j,d}$) of quality determinants (topics) is the variables considered in the analysis. Two separate control charts are provided for each quality determinant. Due to the variability of the number of records in each sample, $\bar{x} - s$ control charts with variable sample size were considered.

In order to track the evolution of quality determinants over time, we introduce the concept of Interval Mean Topical Prevalence ($IMTP_{d,t}$) which represents the average topical prevalence in digital VoC for the *d*-th quality determinants related to the *t*-th sampling period:

$$IMTP_{d,t} = \frac{\sum_{j}^{R_t} \ TP_{j,d}}{|R_t|} \tag{1}$$

where R_t is the set of digital VoC records collected in the *t*-th sampling period, $|R_t|$ is the cardinality of the R_t set (sample size of VoC records).

For each *t*-th sampling period, the sum of the $IMTP_{d,t}$ related to all the identified quality determinants is equal to 1:

$$\sum_{d=1}^{D} IMTP_{d,t} = 1 \qquad \forall\, t \in (1, \dots, T) \tag{2}$$

where *D* is the number of identified topics, and *T* is the total number of sampling period considered.

Table 3 shows an example of the calculation of $IMTP_{d,t}$ for three quality determinants $d = A, B, C$, and three sampling period (January, February and March 2021).

Table 3 - Example of the calculation of $IMTP_{d,t}$ for 3 time periods (January, February and March 2021) and three quality determinants (A,B,C)

Digital VoC record (j)	**Date**	**Sampling period (t)**	**Topical Prevalence ($TP_{j,d}$)** Quality determinant A (d=1)	Quality determinant B (d=2)	Quality determinant C (d=3)	**Interval Mean Topical Prevalence ($IMTP_{d,t}$)** Quality determinant A (d=1)	Quality determinant B (d=2)	Quality determinant C (d=3)
1	January 2021	1	0.8	0.15	0.05	$IMTP_{1,1} = \frac{0.8+0.1+0.8}{3} =$ 0.57	$IMTP_{2,1} =$ 0.33	$IMTP_{3,1} =$ 0.1
2	January 2021	1	0.1	0.7	0.2			
3	January 2021	1	0.8	0.15	0.05			
4	February 2021	2	0.25	0.7	0.05	$IMTP_{1,2} = \frac{0.25+0.45+0.35}{3} =$ 0.35	$IMTP_{2,2} =$ 0.32	$IMTP_{3,3} =$ 0.33
5	February 2021	2	0.45	0.15	0.4			
6	February 2021	2	0.35	0.1	0.55			
7	March 2021	2	0.15	0.65	0.2	$IMTP_{1,3} = \frac{0.15+0.2+0.1}{3} =$ 0.15	$IMTP_{2,3} =$ 0.35	$IMTP_{3,3} =$ 0.5
8	March 2021	2	0.2	0.1	0.7			
9	March 2021	2	0.1	0.3	0.6			

At the *t*-th sampling period, for the *d*-th quality determinant, the standard deviation of topical prevalence can be calculated as (Montgomery, 2020):

$$s_{d,t}^2 = \frac{\sum_j^{R_t}\left(TP_{j,d} - IMTP_{d,t}\right)^2}{|R_t| - 1} \quad (3)$$

With these assumptions, the central line (CL) and the control limits (UCL and LCL) for the s control charts are respectively (Montgomery, 2020):

$$CL_d = \bar{s}_d = \left[\frac{\sum_{t=1}^{T}(|R_t| - 1)s_{d,t}^2}{\sum_{t=1}^{T}|R_t| - T}\right]^{\frac{1}{2}} \quad (4)$$

$$UCL_{d,t} = B_4\, \bar{s}_d \quad (5)$$

$$LCL_{d,t} = B_3 \bar{s}_d \quad (6)$$

Where T is the total number of considered time periods, and B_3 and B_4 are constants tabulated for various values of sample size ($|R_t|$) (Montgomery, 2020).

The central line and variable control limits for the corresponding $\bar{x}$ control chart can be calculated as follows:

$$CL_d = \overline{\overline{x_d}} = \frac{\sum_{t=1}^{T} \sum_{j}^{R_t} \; TP_{j,d}}{\sum_{t=1}^{T} |R_t|} \tag{7}$$

$$\mathrm{UCL}_{d,t} = \overline{\overline{x_d}} + A_3 \bar{s}_d \tag{8}$$

$$LCL_{d,t} = \overline{\overline{x_d}} - A_3 \bar{s}_d \tag{9}$$

A_3 is a constant depending on the sample size ($|R_t|$) (Montgomery, 2020).

As an example, Table 4 and Table 5 show respectively the values obtained for the construction of the $\bar{x}$ and s control charts, for a six-month sampling period, related to the "Charges and fees" ($d = 4$) quality determinant.

Table 4 - Values obtained for the construction of the s control chart for the "Charges and fees" (d=4) quality determinant. Sampling period: 1 semester. S1 and S2 indicate respectively the first and the second semester of each year.

Sampling period (t)	$\|R_t\|$	$s^2_{4,t}$	CL_4	**B3**	**B4**	$LCL_{4,t}$	$UCL_{4,t}$
S1 2006	26	0,0352	0,0771	0,5715	1,4285	0,0441	0,1101
S2 2006	28	0,0439	0,0771	0,5880	1,4120	0,0453	0,1089
S1 2007	46	0,0990	0,0771	0,6820	1,3180	0,0526	0,1016
S2 2007	54	0,0766	0,0771	0,7072	1,2928	0,0545	0,0997
S1 2008	65	0,0583	0,0771	0,7338	1,2662	0,0566	0,0976
S2 2008	51	0,0692	0,0771	0,6985	1,3015	0,0539	0,1003
S1 2009	59	0,0584	0,0771	0,7203	1,2797	0,0555	0,0987
S2 2009	80	0,0518	0,0771	0,7606	1,2394	0,0586	0,0956
S1 2010	66	0,1058	0,0771	0,7359	1,2641	0,0567	0,0975
S2 2010	80	0,0913	0,0771	0,7606	1,2394	0,0586	0,0956
S1 2011	98	0,0894	0,0771	0,7841	1,2159	0,0604	0,0937
S2 2011	79	0,0987	0,0771	0,7590	1,2410	0,0585	0,0957
S1 2012	86	0,0667	0,0771	0,7692	1,2308	0,0593	0,0949
S2 2012	68	0,0830	0,0771	0,7399	1,2601	0,0570	0,0972
S1 2013	72	0,0713	0,0771	0,7474	1,2526	0,0576	0,0966
S2 2013	80	0,0630	0,0771	0,7606	1,2394	0,0586	0,0956
S1 2014	87	0,0722	0,0771	0,7706	1,2294	0,0594	0,0948
S2 2014	94	0,0803	0,0771	0,7794	1,2206	0,0601	0,0941
S1 2015	100	0,0871	0,0771	0,7863	1,2137	0,0606	0,0936
S2 2015	102	0,0839	0,0771	0,7884	1,2116	0,0608	0,0934
S1 2016	102	0,0698	0,0771	0,7884	1,2116	0,0608	0,0934
S2 2016	136	0,0687	0,0771	0,8171	1,1829	0,0630	0,0912
S1 2017	110	0,0716	0,0771	0,7963	1,2037	0,0614	0,0928
S2 2017	82	0,0744	0,0771	0,7636	1,2364	0,0589	0,0953
S1 2018	101	0,0688	0,0771	0,7873	1,2127	0,0607	0,0935
S2 2018	104	0,0776	0,0771	0,7905	1,2095	0,0609	0,0932
S1 2019	60	0,0634	0,0771	0,7227	1,2773	0,0557	0,0985
S2 2019	54	0,1076	0,0771	0,7072	1,2928	0,0545	0,0997

Table 5 - Values obtained for the construction of the $\overline{x}$ control chart, for the "Charges and fees" (d=4) quality determinant. Sampling period: 1 semester. S1 and S2 indicate respectively the first and the second semester of each year.

Sampling period (t)	$\lvert R_t \rvert$	$IMTP_{4,t}$	CL_4	A_3	$LCL_{4,t}$	$UCL_{4,t}$
S1 2006	26	0,0374	0,0759	0,5942	0,0301	0,1218
S2 2006	28	0,0417	0,0759	0,5722	0,0318	0,1201
S1 2007	46	0,0592	0,0759	0,4448	0,0417	0,1102
S2 2007	54	0,0600	0,0759	0,4102	0,0443	0,1076
S1 2008	65	0,0628	0,0759	0,3736	0,0471	0,1047
S2 2008	51	0,0556	0,0759	0,4222	0,0434	0,1085
S1 2009	59	0,0581	0,0759	0,3923	0,0457	0,1062
S2 2009	80	0,0612	0,0759	0,3365	0,0500	0,1019
S1 2010	66	0,0915	0,0759	0,3707	0,0474	0,1045
S2 2010	80	0,0833	0,0759	0,3365	0,0500	0,1019
S1 2011	98	0,0879	0,0759	0,3038	0,0525	0,0994
S2 2011	79	0,0818	0,0759	0,3386	0,0498	0,1020
S1 2012	86	0,0702	0,0759	0,3244	0,0509	0,1010
S2 2012	68	0,0713	0,0759	0,3652	0,0478	0,1041
S1 2013	72	0,0764	0,0759	0,3548	0,0486	0,1033
S2 2013	80	0,0778	0,0759	0,3365	0,0500	0,1019
S1 2014	87	0,0707	0,0759	0,3226	0,0511	0,1008
S2 2014	94	0,0965	0,0759	0,3103	0,0520	0,0999
S1 2015	100	0,0841	0,0759	0,3008	0,0528	0,0991
S2 2015	102	0,0807	0,0759	0,2978	0,0530	0,0989
S1 2016	102	0,0751	0,0759	0,2978	0,0530	0,0989
S2 2016	136	0,0758	0,0759	0,2577	0,0561	0,0958
S1 2017	110	0,0794	0,0759	0,2867	0,0538	0,0980
S2 2017	82	0,0704	0,0759	0,3323	0,0503	0,1016
S1 2018	101	0,0840	0,0759	0,2993	0,0529	0,0990
S2 2018	104	0,0829	0,0759	0,2949	0,0532	0,0987
S1 2019	60	0,0682	0,0759	0,3889	0,0460	0,1059
S2 2019	54	0,1023	0,0759	0,4102	0,0443	0,1076

Figure 2 shows the graphical representation of the $\bar{x}$ control chart for the "Charges and fees" (d=4) quality determinant.

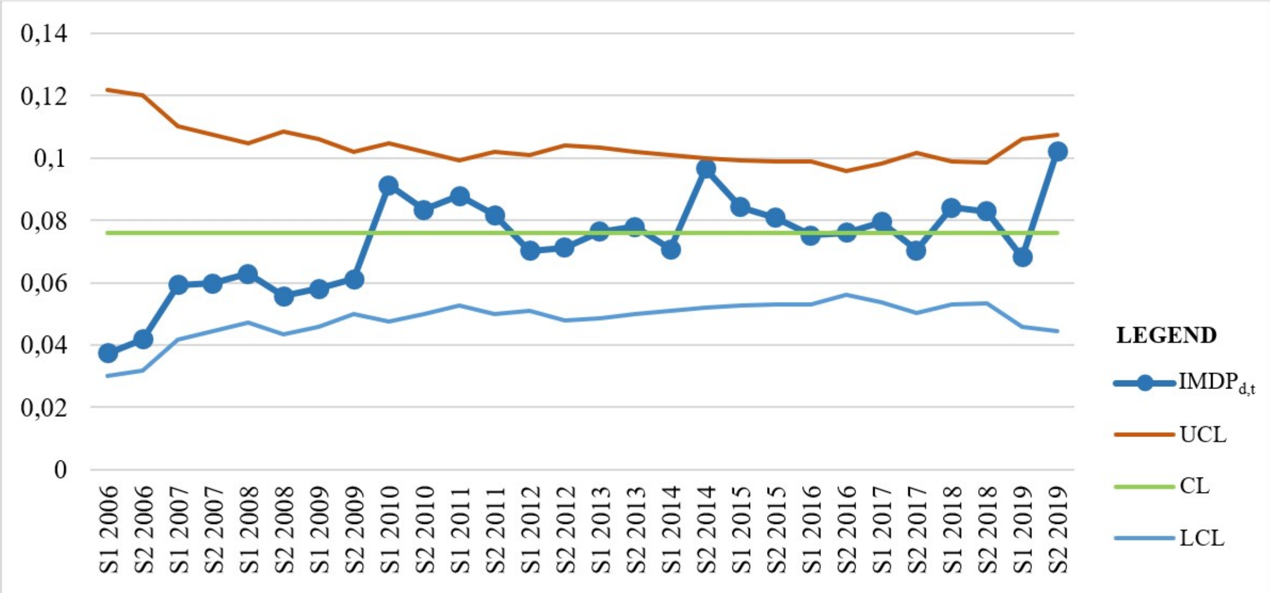

Figure 2 - $\bar{x}$-control charts ($IMTP_{4,t}$) for the "Charges and fees" (d=4) quality determinant. Sampling period: 1 semester. S1 and S2 indicate respectively the first and the second semester of each year.

We observe that none of the points falls outside the control lines. However, according to the Western Electric rules, an out-of-control is observed, due to a high number of consecutive points (from S1 2006 to S2 2009), falling on the same side of the central line (Montgomery, 2020).

Figure 3 shows the s-control chart for the "Charges and fees" (d=4) quality determinant.

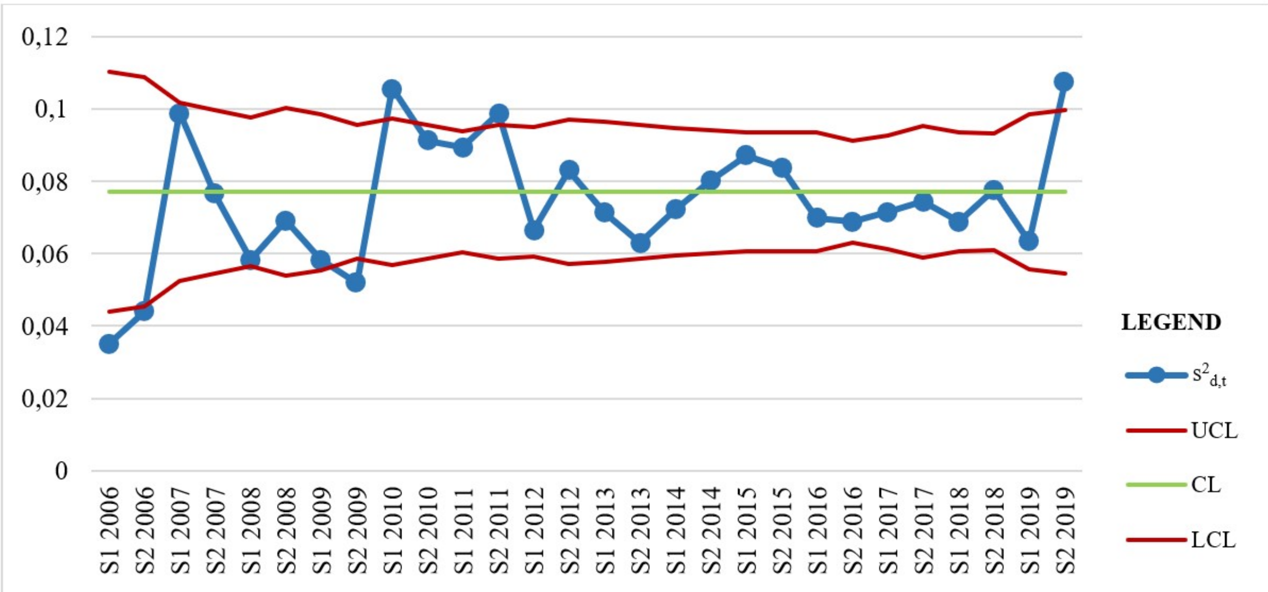

Figure 3 – $\boldsymbol{s}$-control charts for the "Charges and fees" (d=4) quality determinant. Sampling rate: 1 semester. S1 and S2 indicate respectively the first and the second semester of each year.

In this case, several observations fall outside the control limits, highlighting an anomalous variability in the topical prevalence of the "Charges and fees" (d=4) quality determinants. The causes of out-of-control must be analyzed in detail to avoid their recurrence. As an example, let us consider the last point of the control charts, the increase in s^2 is caused by failures in the application of charges and fees. A detailed analysis of the process may allow to identify specific causes.

3.3. p-control charts for car-sharing quality determinants

In this section, we provide a second way to analyze topical prevalence. As an example, let's try to monitor the fraction of "winnings" of a particular quality determinant over the others. By a "winning" quality determinant is meant a quality determinant whose *topical prevalence*, within a record (customer review), prevails over the others. We may consider the "winning" quality determinant as the most representative of the digital VoC record. Each review can be associated with only one "winning" determinant. The topical prevalence of the winning quality determinant can be set to the value 1 through a binary transformation. Conversely, the topical prevalence of the remaining $(D-1)$ quality determinants can be set to the value 0.

For each j-th digital VoC record, the "winning" quality determinant is the one that shows the highest topical prevalence:

$$V_{j,d} = \begin{cases} 1 & if \quad TP_{j,d} = Max_j(TP_{j,d}) \\ 0 & if \quad TP_{j,d} \neq Max_j(TP_{j,d}) \end{cases} \tag{10}$$

Table 6 shows an example of this binary transformation.

Table 6 - Example of binary transformation for the development of a p-control chart for quality determinants

Quality determinants	A	B	C	D
$TP_{j,d}$	0.8	0.10	0.07	0.03
$V_{j,d}$	1	0	0	0

As before, the sum of the topical prevalences associated with a j-th digital VoC record is equal to 1:

$$\sum_{d=1}^{D} V_{j,d} = 1 \qquad \forall\, j \in (1, \dots, J) \tag{11}$$

Once the binary transformation of all reviews has been performed, it is possible to compute the values of $\bar{p}_{d,t}$, i.e., the "winning" percentage of the d-th quality determinant in the t-th sampling period:

$$p_{d,t} = \frac{\sum_j^{R_t} V_{j,d}}{|R_t|} \qquad \forall\, t \in (1, \dots, T) \tag{12}$$

where R_t is the set of digital VoC collected in the i-th sampling period, $|R_t|$ is the cardinality of the R_t set.

The central line (CL) and the control limits (UCL, LCL) of the p-control chart are defined as follows (Montgomery, 2020):

$$CL_d = \overline{p_d} = \frac{\sum_{t=1}^{T}|R_t| \cdot \bar{p}_{d,t}}{\sum_{t=1}^{T}|R_t|} \tag{13}$$

$$UCL_{d,t} = \overline{p_d} + 3\sqrt{\frac{\overline{p_d}\,(1-\overline{p_d})}{|R_t|}} \tag{14}$$

$$LCL_{d,t} = \overline{p_d} - 3\sqrt{\frac{\overline{p_d}(1-\overline{p_d})}{|R_t|}} \tag{15}$$

As an example, Table 7 shows the values obtained for the development of the p-control chart for a six-month sampling period, related to the "Charges and fees" (d=4) quality determinant.

Table 7 - Values obtained for the construction of a p-control chart for the "Charges and fees" (d=4) quality determinant. Sampling rate: 1 semester. S1 and S2 indicate respectively the first and the second semester of each year.

Sampling period (t)	$\lvert R_t \rvert$	$p_{d,t}$	CL_4	$LCL_{4,t}$	$UCL_{4,t}$
S1 2006	26	0	0.0995	0	0,2756
S2 2006	28	0,0357	0.0995	0	0,2692
S1 2007	46	0,0652	0.0995	0	0,2319
S2 2007	54	0,1111	0.0995	0	0,2217
S1 2008	65	0,0615	0.0995	0	0,2109
S2 2008	51	0,0588	0.0995	0	0,2253
S1 2009	59	0,0338	0.0995	0	0,2164
S2 2009	80	0,05	0.0995	0	0,1999
S1 2010	66	0,2121	0.0995	0	0,2100
S2 2010	80	0,1750	0.0995	0	0,1999
S1 2011	98	0,1326	0.0995	0,0088	0,1902
S2 2011	79	0,1265	0.0995	0	0,2005
S1 2012	86	0,127	0.0995	0,0026	0,1963
S2 2012	68	0,0294	0.0995	0	0,2084
S1 2013	72	0,0833	0.0995	0	0,2053
S2 2013	80	0,1125	0.0995	0	0,1999
S1 2014	87	0,0689	0.0995	0,0032	0,1958
S2 2014	94	0,1276	0.0995	0,0069	0,1921
S1 2015	100	0,14	0.0995	0,0097	0,1893
S2 2015	102	0,1176	0.0995	0,0106	0,1884
S1 2016	102	0,1078	0.0995	0,0106	0,1884
S2 2016	136	0,1176	0.0995	0,0225	0,1765
S1 2017	110	0,0909	0.0995	0,0139	0,1851
S2 2017	82	0,0487	0.0995	0,0003	0,1987
S1 2018	101	0,0792	0.0995	0,0101	0,1889
S2 2018	104	0,125	0.0995	0,0114	0,1876
S1 2019	60	0,06667	0.0995	0	0,2154
S2 2019	54	0,07407	0.0995	0	0,2217

A graphical representation of the p-control charts for the "Charges and fees" (d=4) quality determinant is reported in Figure 4.

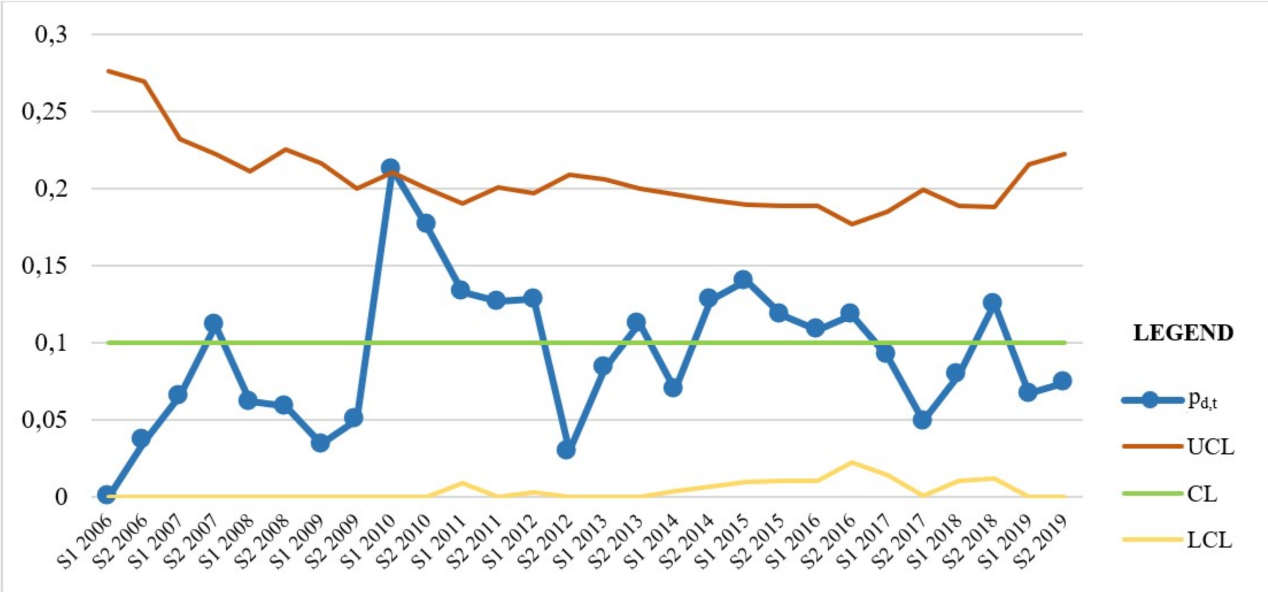

Figure 4 - **p**-control chart for the quality determinant "Charges and fees" (d=4).

In this case, the p-control chart shows a points outside the control limits. This occurs in the first semester of 2010 (S1 2010). Again, the causes of the out-of-control point must be analyzed in detail to avoid its recurrence. In this case the point does not represent an anomalous situation.

4. DISCUSSION AND CONCLUSIONS

The purpose of the current study was to investigate the applicability of Statistical Process Control tools for digital VoC analysis. Specifically, two different types of control charts, $\bar{x} - s$ and p, were considered to monitor the evolution of quality determinants over time. Control charts were developed based on the outputs generated by a topic modelling algorithm applied to a digital VoC database. A real case study concerning the car-sharing companies supported the explanation of the proposed approaches.

The results of this preliminary investigation show that control charts can provide valuable support in monitoring the quality determinants of products and services over time. The two types of control charts applied in this study are based on different principles, and their use has shown many differences. $\bar{x} - s$ control charts receive as input the average topical prevalence values generated by the topic modelling algorithm. In contrast, p control charts require the definition of the most discussed quality determinant for each VoC record. The introduction of the binary transformation may present some critical issues since it involves a pre-elaboration of the considered topical prevalences. In p-control charts, each quality determinant is mutually exclusive within a single digital VoC record; on the contrary, $\bar{x} - s$ control charts can consider several quality determinants that could be relevant within a single digital VoC record. This second option seems to be more useful in practical contexts. Overall, on the basis of this preliminary study, it appears that control charts for variables can provide more effective support in identifying out-of-control conditions of quality determinants, taking into account all information generated by the topic modelling algorithm.

SPC tools applied to digital VoC can support designers of products and services by providing a clear understanding of the evolution of quality determinants, allowing them to directly intervene in the design process in order to correct anomalies or unforeseen situations highlighted by the control charts. However, much more work will need to be done to successfully implement SPC in digital VoC analysis. The main limitation of this study is that the control charts proposed are suitable for monitoring stationary processes. However, some quality determinants show trends in the topical prevalence (e.g. a constant increase or decrease of $IMTP_{d,t}$ over time). Regression control charts or Moving Average control charts may represent valid tools to analyze these different behaviors.

Moreover, other metadata associated with the digital VoC (for example, record ratings) may be considered in the analysis. Further research will be directed on how to integrate this information to support designers to detect anomalous situations.

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6. REFERENCES

Aguwa, C. C., Monplaisir, L., & Turgut, O. (2012). Voice of the customer: Customer satisfaction ratio based analysis. *Expert Systems with Applications*, *39*(11), 10112–10119.

Ashton, T., & Evangelopoulos, N. (2012). Control charts for customer comments: a case study and a research agenda. *Proceeding of the Southwest Decision Sciences Institute*, 661–669.

Ashton, T., Evangelopoulos, N., & Prybutok, V. (2014). Extending monitoring methods to textual data: a research agenda. *Quality & Quantity*, *48*(4), 2277–2294.

Ashton, T., Evangelopoulos, N., & Prybutok, V. R. (2015). Quantitative quality control from qualitative data: control charts with latent semantic analysis. *Quality & Quantity*, *49*(3), 1081–1099.

Bandaru, S., Gaur, A., Deb, K., Khare, V., Chougule, R., & Bandyopadhyay, P. (2015). Development, analysis and applications of a quantitative methodology for assessing customer satisfaction using evolutionary optimization. *Applied Soft Computing*, *30*, 265–278.

Barravecchia, F., Mastrogiacomo, L., & Fiorenzo, F. (2020). Categorizing quality determinants in mining user-generated contents. *Sustainability (Switzerland)*, *12*(23), 1–12, 9944.

Barravecchia, F., Mastrogiacomo, L., & Franceschini, F. (2020b). Identifying car-sharing quality determinants: A data-driven approach to improve engineering design. *International Conference on Quality Engineering and Management*, 125–140.

Barravecchia, F., Mastrogiacomo, L., & Franceschini, F. (2021). Digital voice-of-customer processing by topic modelling algorithms: insights to validate empirical results. *International Journal of Quality & Reliability Management*, ahead-of-print (doi: 10.1108/IJQRM-07-2021-0217).

Berry, M. W., & Kogan, J. (2010). *Text mining: applications and theory*. John Wiley & Sons.

Blei, D. M. (2012). Probabilistic topic models. *Communications of the ACM*, *55*(4), 77–84.

Blei, D. M., Ng, A. Y., & Jordan, M. I. (2003). Latent dirichlet allocation. *Journal of Machine Learning Research*, *3*, 993–1022.

Carnerud, D. (2020). The quality movement's three operational paradigms: a text mining venture. *The TQM Journal*, *32*(6), 1577–1598.

Chen, K.-S., Chang, T.-C., Wang, K.-J., & Huang, C.-T. (2015). Developing control charts in monitoring service quality based on the number of customer complaints. *Total Quality Management & Business Excellence*, *26*(5–6), 675–689.

Elg, M., Birch-Jensen, A., Gremyr, I., Martin, J., & Melin, U. (2021). Digitalisation and quality management: problems and prospects. *Production Planning & Control*, *32*(12), 990–1003.

Franceschini, F. (2002). Learning curves and p-charts for a preliminary estimation of asymptotic performances of a manufacturing process. *Total Quality Management*, *13*(1), 5–12.

Franceschini, F., Galetto, M., & Turina, E. (2009). Service quality monitoring by performance indicators: A proposal for a structured methodology. *International Journal of Services and Operations Management*, *5*(2), 251–273.

Freeman, G., & Radziwill, N. (2018). Voice of the Customer (VoC): A Review of Techniques to Reveal and Prioritize Requirements for Quality. *Journal of Quality Management Systems*, *17*, 1–29.

Gregorio, R., & Cronemyr, P. (2011). From expectations and needs of service customers to control chart specification limits. *The TQM Journal*, *23*(2), 164–178.

Hallencreutz, J., & Parmler, J. (2021). Important drivers for customer satisfaction – from product focus to image and service quality. *Total Quality Management & Business Excellence*, *32*(5–6), 501–510.

Izogo, E. E., & Ogba, I.-E. (2015). Service quality, customer satisfaction and loyalty in automobile repair services sector. *International Journal of Quality & Reliability Management*, *32*(3), 250–269.

Jach, P., Antony, J., Thomson, S. P., Cudney, B., & Furterer, S. (2021). Voice of the customer as a tool for service quality analysis in public transport. *The TQM Journal*, ahead-of-print(doi:10.1108/TQM-05-2021-0134).

Kamsu-Foguem, B., Rigal, F., & Mauget, F. (2013). Mining association rules for the quality improvement of the production process. *Expert Systems with Applications*, *40*(4), 1034–1045.

Kumar, A., & Anjaly, B. (2017). How to measure post-purchase customer experience in online retailing? A scale development study. *International Journal of Retail & Distribution Management*, *45*(12), 1277–1297.

Liang, Q., & Wang, K. (2019). Monitoring of user-generated reviews via a sequential reverse joint sentiment-topic model. *Quality and Reliability Engineering International*, *35*, 1180–1199.

Lo, S. (2008). Web service quality control based on text mining using support vector machine. *Expert Systems with Applications*, *34*(1), 603–610.

Lysenko-Ryba, K., Zimon, D., Madzík, P. and Šírová, E. (2022). Examination of aspects of pro-consumer refund system. *The TQM Journal*, Ahead-of-print. DOI:10.1108/TQM-06-2021-0182

Mastrogiacomo, L., Barravecchia, F., Franceschini, F., & Marimon, F. (2021). Mining quality determinants of Product-Service Systems from unstructured User-Generated Contents: the case of car-sharing. *Quality Engineering*, *33*(3), 425–442.

Matzler, K., & Sauerwein, E. (2002). The factor structure of customer satisfaction: An empirical test of the importance grid and the penalty-reward-contrast analysis. *International Journal of Service Industry Management*, *13*(4), 314–332.

McColl-Kennedy, J., & Schneider, U. (2000). Measuring customer satisfaction: Why, what and how. *Total Quality Management*, *11*(7), 883–896.

Montgomery, D. C. (2020). *Introduction to statistical quality control*. 8th edition, John Wiley & Sons, New York.

Mukherjee, S. P. (2019). *Quality, Domains and Dimensions*. Springer.

Psarommatis, F., Prouvost, S., May, G., & Kiritsis, D. (2020). Product quality improvement policies in industry 4.0: characteristics, enabling factors, barriers, and evolution toward zero defect manufacturing. *Frontiers in Computer Science*, *2*, 26.

Roberts, M. E., Stewart, B. M., & Tingley, D. (2019). STM: R package for structural topic models. *Journal of Statistical Software*, *91*(2), 1–40.

Su, Y., & Hwang, J.-S. (2020). Integration of customer satisfaction and sustained use of a product for value assessment. *Total Quality Management & Business Excellence*, *31*(15–16), 1760–1773.

Sweeney, J. C., Soutar, G. N., & Mazzarol, T. (2008). Factors influencing word of mouth effectiveness: receiver perspectives. *European Journal of Marketing*, *42*(3/4), 344–364.

Szwejczewski, M., Goffin, K., & Anagnostopoulos, Z. (2015). Product service systems, after-sales service and new product development. *International Journal of Production Research*, *53*(17), 5334–5353.

Wang, P. (2015). Exploring the influence of electronic word-of-mouth on tourists' visit intention: A dual process approach. *Journal of Systems and Information Technology*, *17*(5), 381–395.

Wang, Y., & Tseng, M. M. (2011). Integrating comprehensive customer requirements into product design. *CIRP Annals - Manufacturing Technology*, *60*(1), 175–178.

Xu, W., Guo, C., Guo, S., Wang, L., & Li, X. (2021). A novel quality comprehensive evaluation method based on product gene for solving the manufacturing quality tracking problem of large equipment. *Computers & Industrial Engineering*, *152*, 107032.

Product complexity and quality in assembly processes: state-of-art and challenges for Human-Robot Collaboration

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STRUCTURED ABSTRACT

Purpose - It is widely accepted in quality management that product complexity is a primary cause of defects. A primary goal of this work is to provide a comprehensive review of complexity assessment methods to highlight different approaches and their application purposes. Moreover, the spread of collaborative robotics in industrial environments has also led to the consideration of a new definition of assembly complexity. This article attempts to fill this gap, with the specific aim of understanding which of the available methods may be suitable for modelling “complexity” in human-robot collaboration (HRC).

Design/methodology/approach – A systematic literature review of complexity assessment methods in manufacturing is carried out. From this analysis, three main approaches to complexity assessment emerged. A practical case is then introduced to test each of the three previous approaches and to highlight their strengths and weaknesses, with a special focus on their future adaptation to a collaborative assembly process.

Findings - To date, none of complexity assessment methods is specifically able to face the problem of interaction between agents (i.e., humans and robots). Only system-centered approaches hypothesize a holistic view of complexity, including some variables that are also crucial in the assessment of human-robot collaboration.

Originality/value – This article aims to extend the concept of industrial quality to HRC. In this framework, it cannot be ignored the fact that the dynamics of interaction between agents can equally influence both process and product quality.

Keywords: Complexity assessment, Assembly process, Quality control, Human-Robot collaboration

Paper type: Research paper

1. INTRODUCTION

The world of manufacturing has been facing new challenges in recent years. The spread of Industry 4.0 principles has put humans back at the center of manufacturing processes, introducing the concept of human-centered manufacturing (Mital and Pennathur, 2004; Oztemel and Gursev, 2020; Xu *et al.*, 2018). One of the most promising enabling technologies of this transition is collaborative robotics. Unlike traditional robots, humans and cobots work simultaneously in a shared workspace (Bauer *et al.*, 2008; Goodrich and Schultz, 2008). In this way, humans can be replaced by machines in the most exhausting and repetitive operations, but at the same time they make up for the rigidity of robots with their flexibility and dexterity in the most complicated operations. Collaborative robotics is widely used in assembly processes where humans and cobots cooperate basing on a predefined assignment of tasks with the common goal of assembling a product. In literature, this process is known as collaborative (or HRC) assembly. Considering this, traditional quality control paradigms should also be revisited. Many studies showed that structurally complex products can increase the probability of defects in manually assembled products (Genta *et al.*, 2018; Su *et al.*, 2009; Verna *et al.*, 2021). Although product complexity remains an important source of defects, it is necessary to adopt a multidimensional approach for the assessment of complexity in a collaborative assembly, including variables such as safety, human-robot communication, task organization, physical and psychological well-being of operators. While much research has been done on the assessment of complexity of a manual assembly, there is a gap of knowledge about effects of the variables that may impact the complexity of collaborative assembly. The complexity of human-robot interaction, indeed, may negatively affect the entire assembly process and lead to the occurrence of new process defects and thus product defects. This work attempts to preliminarily answer the following research question*: Are existing complexity assessment methods suitable to analyze HRC in collaborative settings?* This paper is organized in the following way. The first section provides an extensive literature review on assembly complexity methods, identifying three main approaches. In the second part a practical case study is introduced to comparatively evaluate different approaches. The final section concerns a preliminary analysis performed to identify which crucial dimensions in assessing the complexity of collaborative assembly would be covered or uncovered by existing methods.

2. ASSEMBLY COMPLEXITY: A LITERATURE REVIEW

This section contains an extensive literature overview on methods for assessing manufacturing complexity in assembly tasks.

2.1. Methodology

The literature review is based on the analysis of a sample of journal articles obtained throughout the following Scopus query string: *"(TITLE-ABS-KEY (("structural complexity" OR "product complexity" OR "process complexity" OR "task complexity" OR "complexity analysis" OR "complexity metrics" OR "Perceived production complexity" OR "operational complexity" OR "manufacturing complexity" OR "production complexity") AND ("manufacturing" OR "production" OR "assembly"))) AND (LIMIT-TO (SUBJAREA , "ENGI")) AND (LIMIT-TO (DOCTYPE , "ar"))*". The rationale behind the definition of this query string was to include the following elements:

1. core content: a list of keywords concerning complexity assessment and metrics
2. scope: production systems and more specifically assembly
3. subject area: only papers related to engineering fields
4. document type: article

The initial database was composed of 733 documents from 1970 until 2021. Through a first analysis of titles and abstracts, only documents concerning product and operational complexity from 2010 to 2021 were included, reducing the initial set of 733 papers to 94 significant papers. Hence, papers not referring to complexity in assembly tasks were excluded. After this second filtering, 18 significant papers remained. The last phase of this literature review involved snowballing analysis, i.e., a global analysis of references and citations of the papers in scope, obtaining a final set of 33 documents. In Figure 1 a diagram flow illustrating all the phases of the state-of-the-art analysis is represented.

Basing also on taxonomies already proposed across years (Alkan, Vera, Ahmad, Ahmad, *et al.*, 2018; EIMaraghy and Urbanic, 2004) , three macro areas of complexity methods in assembly processes were identified:

- Product-centered complexity: it includes methods that evaluate complexity by focusing mainly on (i) the geometrical and dimensional features of products and (ii) the necessary time to handle parts and perform a specific assembly task.
- Information-centered complexity: it includes methods that regard complexity as positively correlated to the quantity and variety of information the assembly operator manages during the process.

- System-centered complexity: it includes methods that propose a holistic view of complexity, mainly influenced by variables external to the specific assembly task, such as production layouts, scheduling, external demand, ergonomics, skills, etc.

In Tables 1,2 and 3 the main methods analyzed for each approach are provided.

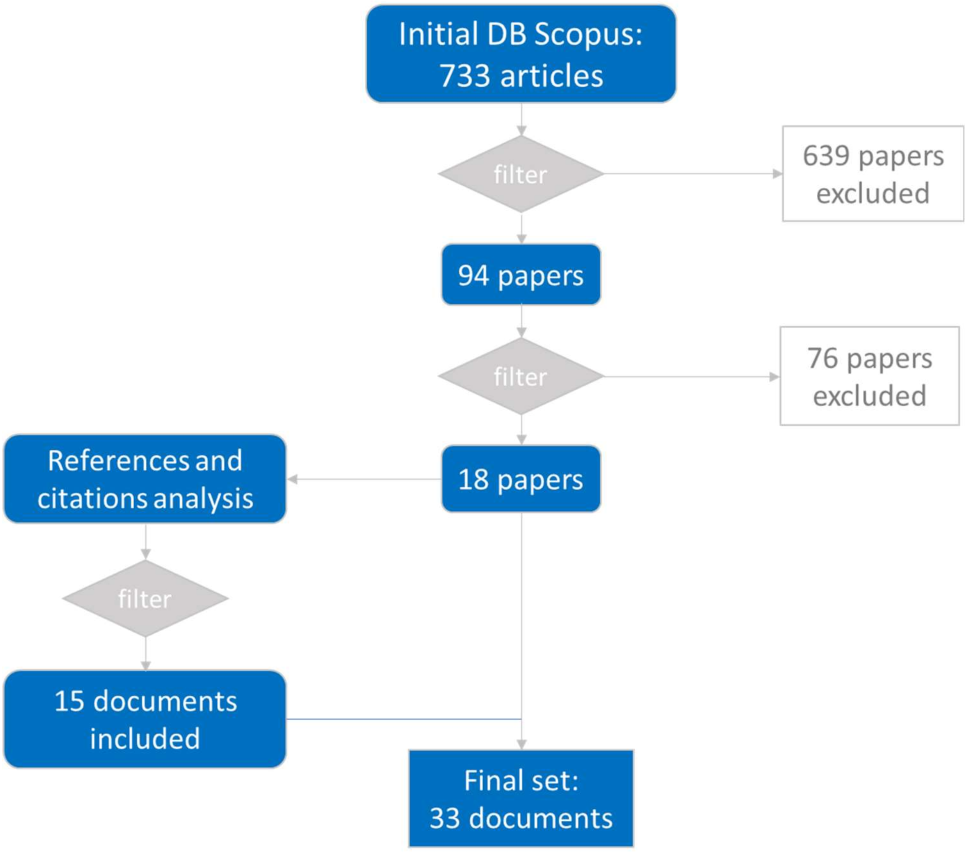

Figure 1 - Diagram flow of literature review analysis about complexity methods in assembly processes

2.2. Product-Centered Complexity

Product-centered complexity models relate complexity to product characteristics. Geometrical and dimensional features of components may affect the difficulty for operators to handle and assemble parts, (Alkan, Vera, Ahmad and Harrison, 2018). Most of methods described in this section derived from principles of design for assembly (Boothroyd, 1994). Design for Assembly (DFA) was introduced with the purpose of increasing assembly efficiency. DFA consists of a set of criteria for the design of a product aimed at reducing assembly times and thus generating benefits in terms of costs and quality (Boothroyd, 1994). Hinckley (1994) proposed an assembly complexity factor depending on assembly times and number of operations. By correlating complexity factor to number of defects detected in the final product, Hinckley (1994) underlined the importance of controlling complexity as a way to reduce costs and improve quality. This model was subsequently modified by Shibata (2002) who added to Hinckley's factor a new complexity coefficient, namely design-based complexity factor, based on DFA principles developed by Sony Corporation. Su et al. (2009) modified Shibata's design-based complexity factor introducing a new factor calculated with AHP method, using complexity criteria proposed by Ben Arieh (1994). This new approach extended the possibility to calculate a design based complexity factor to all electronic and mechanical products (Su *et al.*, 2009). The process-based complexity factor Cf_{Pi} and the design-based complexity factor Cf_{Di}, first introduced by Shibata (2002) and the modified by Su et al. (2009), are the followings:

$$Cf_{P,i} = \sum_{j=1}^{N_{ai}} SST_{ij} - t_0 N_{ai} \tag{1}$$

$$Cf_{D,i} = \sum_{p=1}^{l} w_p \cdot \frac{1}{e} \sum_{k=1}^{e} A_{kpi} \tag{2}$$

Where:

- SST_{ij} is the standard time of job j in workstation i
- t_0 is a threshold assembly time and N_{ai} is the number of jobs in workstation i
- w_p is the weight of the parameter p obtained by AHP method
- e is the total number of evaluators and l the total number of parameters
- A_{kpi} represents the evaluation of parameter p for workstation i given by the evaluator k.

Another significant approach to assembly complexity was proposed by Sinha and de Weck (2014) who developed a quantitative measure of product complexity, using an analogy with molecular systems in quantum mechanics. Complexity of a product is determined by complexity of single components C_1, complexity of interfaces C_2 and topological complexity C_3 as follows (Sinha and de Weck, 2014):

$$C = C_1 + C_2 C_3 \tag{3}$$

A detailed description of (3) is given in section 3.1. Subsequently, Alkan (2019) assimilated complexity of components to the time necessary to handle single parts, complexity of interfaces to the time for joining them and topological complexity to the energy of the adjacency matrix representing the structure of the assembled product. Recently, other studies (Genta *et al.*, 2018; Verna *et al.*, 2021) proposed statistical models to predict product defects using structural complexity factors developed by Su et al. (2009) and Alkan et al. (2018).
A different methodology was proposed by Mathieson (2013) who identified three groups of product complexity metrics derived from graph theory (i.e., size, path length and decomposition) and used them to predict assembly times of products.

Table 1 – List of the main product-centered methods

Year	Authors	Main results
1993	Hinckley M.	Definition of a complexity factor depending on total assembly times and number of assembly operations
1994	Ben-Arieh, D.	Set of geometrical-based and type of contact parameters influencing difficulty of assembly operations
2002	Shibata, H.	Definition of a design-based complexity factor and a process-based complexity factor for electronic products
2010	Su Q., et al.	Mathematical model to predict defects based on design and process complexity factors for electro-mechanical products
2012	Mathieson J.L., et al.	Application of graph theory to model product complexity and estimate assembly time
2014	Sinha, K.	Definition of a new model of product complexity through structural, interfaces and topological complexity
2017	Alkan B., et al.	Application of DFA principles to assess structural, interfaces and topological complexity in electronic industry
2018	Genta et al.	Assembly defect prediction using Shibata and Su's models
2019	Alkan B.	Empirical investigation of correlation between perceived assembly complexity and product complexity based on assembly times
2021	Verna et al.	Defect monitoring of assembled products using Alkan's complexity model

2.3. Information-centered methods

Information-centered approach includes methods that relate complexity to quantity and variety of information managed. With reference to a specific assembly task, information means product variants, variety of actions, variety of fasteners, variety of tools, etc. Operators' choice becomes more complex when the variety of information increases. The common feature of methods belonging to this type of approach is the quantification of information, recurring to Shannon's theory (Shannon, 1948). Many studies used the concepts of information theory, such as entropy, to measure complexity in manufacturing systems. The analogy between complexity in assembly task and the information theory is based on the assumption that higher level of complexity means greater quantity of information to be managed (EIMaraghy and Urbanic, 2004; ElMaraghy and Urbanic, 2003). Product variety was a crucial variable in assembly process design for Fujimoto et al. (2003) who defined an entropic measure aimed at managing complexity in an automotive manufacturing environment. A similar analogy was used by Zhu et al. (2008), adapting Shannon's entropy to measure the complexity of operators' choice in mixed model assembly lines where many product variants have to be managed. Ameri et al. (2008) summarized design complexity in two different measures, a size complexity metric based on entropic methods and a decomposability metric derived from graph theory. Wang and Hu (2010) modified the concept of entropy theorized by Zhu et al. (2008) and developed an entropic measure to model operator choice at assembly stations. The authors also introduced a novel idea of complexity based on human and mental fatigue (Wang and Hu, 2010) subsequently used in a non-linear programming algorithm to minimize manufacturing complexity (Wang *et al.*, 2013). Samy and ElMaraghy (2010) hypothesized complexity related to specifical geometric characteristics of each part involved, to the number of parts composing the final product, and to the variety of components an operator faces during assembly. The quantity and the variety of information that an operator manages is proportional to the quantity and variety of parts requested to assemble the final product (Samy and ElMaraghy, 2010, 2012). Equation (4) represents Samy and ElMaraghy's complexity factor.

$$C_{product} = \left[\frac{n_p}{N_p} + CI_{product}\right][\log_2(N_p + 1)] + \left[\frac{n_s}{N_s}\right][\log_2(N_s + 1) \quad (4)$$

Where:

- n_p is the number of unique parts and N_p is the total number of parts
- n_s is the number of unique fasteners and N_s is the total number of fasteners
- $CI_{product}$ is a complexity index (calculated using DFA coefficients).

Modrak et al. (2014) assumed complexity correlated to possible different configurations of products. In this case, a product with many possible different configurations and optional components increases task difficulty and consequently the range of choices for operators. Another approach is proposed by Park and Okudan Kremer (2015) who defined a measure of static complexity in manufacturing through a combination of the mathematical definition of information content with the concept of "degree of commonality" for product families (Simpson and D'Souza, 2004).

Table 2 – List of the main information-centered methods

Year	Authors	Main results
2003	ElMaraghy W.H. and Urbanic R.J.	Model of product complexity based on quantity, variety and content of information managed by assembly operators
2003	Fujimoto H., et al.	Definition of an entropy-based complexity metrics to manage varieties in assembly operations
2004	ElMaraghy W.H. and Urbanic R.J.	Elaboration of an entropy-based metric to assess operational complexity depending on operators' physical and cognitive effort
2008	Ameri F., et al.	Introduction of size and coupling complexities using respectively information entropy metrics and graph theory
2008	Zhu X., et al.	Development of an information-based complexity factor based on product variants
2010	Samy S.N. and ElMaraghy H.	Mathematical model to assess assembly complexity based on quantity and variety of parts and fasteners composing a product
2010	Wang H. and Hu S.J.	Measure of manufacturing complexity based on quantity and variety of operators' choices of assembly activities
2012	Samy S.N. and Elmaraghy H.A.	Information-based model to describe the correlation between parts and assembly equipment complexity
2013	Wang H., et al.	Definition of a manufacturing complexity measure based on the mix of product variants assembled in a specific workstation
2014	Modrak V., et al.	Assembly complexity measure based on possible different combination of customized products
2015	Park K. and Okudan Kremer G.E.	Definition of a complexity metric combining information theory and the concept of commonality of product families

2.4. *System-centered approach*

In literature some studies extended the concept of production complexity beyond the specific assembly task. System-centered approach aims at providing an overall view of manufacturing complexity, also considering external product demand, production layouts and scheduling, working and ergonomics conditions as sources of complexity. Due to variety of dimensions assessed in this approach, many different methodologies were used, e.g., information theory, graph theory, surveys, and interviews. Zaeh (2009) proposed a multidimensional analysis to evaluate complexity, consisting of temporal measures, cognitive and knowledge-based factors. Jenab and Liu (2010) elaborated a mathematical method to create a graph in which nodes represented products, while connections between nodes depended on processing times, type of resources and skills required. Abad and Jin (2011) built a quantitative manufacturing complexity metric based on demanded product variety. Concerning budgeting and resource allocation, this contributed to focus on more critical stations and products. Chryssolouris et al. (Chryssolouris *et al.*, 2013) elaborated a graph theory-based measure of manufacturing complexity proportional to machines, products, processes and resources. Information theory principles was also applied to manufacturing systems to provide a method to assess an overall complexity, also considering quantity and variety of machines, material handling equipment and buffers involved in production systems (Samy and ElMaraghy, 2012). ElMaraghy et al. (2014) introduced a method to evaluate structural complexity of a manufacturing layout. In this work the authors proposed a set of parameters to calculate the complexity of the graph representing the flow of material within a manufacturing system (ElMaraghy *et al.*, 2014). Al-Zuheri (2013) connected complexity of assembly tasks to variance of tasks determined by operating times, workers' skills and fatigue. Concerning layout optimization, Modrak and Soltysova (2018) elaborated a new operational complexity parameter derived from an entropic coefficient that takes into account total number of parts, machines and operations and further used to find an optimal production layout. More recently, Busogi et al. (2019) defined a complexity entropic measure as the probability of receiving a demand of product variants with refers to the total demand of a certain product and used it to minimize complexity of product sequencing. Another common approach in assessing the complexity of manufacturing is the use of interviews and surveys. Mattsson et al. (2014, 2016, 2020) introduced a novel index, called "Complexity index" (CXI). Unlike the previous methods analyzed which attempt to objectively quantify complexity, CXI aimed at measuring perceived production complexity, interviewing workers on five topics, i.e., product variants, layout, work content, tools, and information. A similar approach was followed with the introduction of basic complexity criteria, namely CXB (Falck, Tarrar, *et al.*, 2017; Falck, Örtengren, *et al.*, 2017a, 2017b). The number of criteria fulfilled determines the complexity level of the assembly task (Falck, Tarrar, *et al.*, 2017; Falck, Örtengren, *et al.*, 2017a). Finally, Martinez Olvera (2020) developed an entropic value aimed at measuring manufacturing complexity influenced by product variety and industry 4.0 paradigms.

Table 3 – List of the main system-centered methods

Year	Authors	Main results
2009	Zaeh M.F., et al.	Multi-dimensional measure of assembly complexity including also cognitive and knowledge aspects
2010	Jenab K. and Liu D.	Graph-based model to assess system complexity depending on assembly times, resources, and operators' skills
2011	Abad A.G. and Jin J.	Elaboration of a communication-based complexity model depending on product demand
2012	Samy S.N. and ElMaraghy H.	Development of a system complexity measure based on production layouts
2013	Al-Zuheri A.	Introduction of workers' skills and human fatigue in the assessment of assembly complexity
2013	Chryssolouris G., et al.	Definition of a system graph-based complexity measure and analysis of the relationship between system complexity and flexibility
2014	Elmaraghy H., et al.	Mathematical model to assess the complexity of manufacturing layouts
2016	Mattsson S., et al.	Analysis of workers' perceived production complexity using a questionnaire-based method (i.e., CXI assessment)
2017	Falck A.-C., et al.	Definition of a set of complexity criteria to assess assembly workstations
2018	Modrak V. and Soltysova Z.	Elaboration of an entropy-based complexity coefficient based on production system organization
2019	Busogi M., et al.	Entropy-based method depending on external demand of customized products
2020	Martínez-Olvera C.	Development of a complexity measure based on both product variety and the introduction of Industry 4.0 features in production organization

3. A PRACTICAL CASE STUDY: THE MANUAL ASSEMBLY OF A SMALL WATER PUMP

After the general overview of the models provided to analyze complexity, in this section a case study concerning the assembly of a diaphragm water pump is presented (see Figure 2 and Figure 3). The detailed decomposition of the water pump in sub parts and their quantities is provided in Table 4.

Table 4 - Details of parts and quantities of a diaphragm water pump

Parts and fasteners	Code	Quantities
Engine block	EB	1
Rubber feet	RF	1
Ring	R	1
Flange 1	F1	1
Flange 2	F2	1
Diaphragm	D	1
Cover with valves	CV	1
Cover	C	1
Pressure switch	PS	1
Pressure switch diaphragm	PSD	1
Filter	F	1
Flow adapter	FA	2
Screws type 1	S1	2
Screws type 2	S2	6
Screws type 3	S3	3
Screws type 4	S4	3

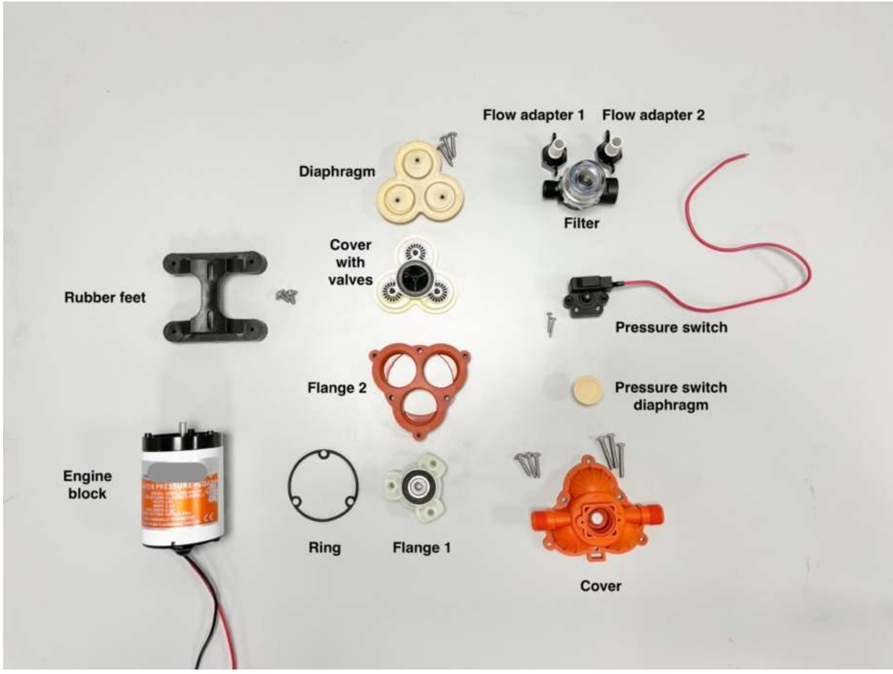

Figure 2 – Parts decomposition of a diaphragm water pump

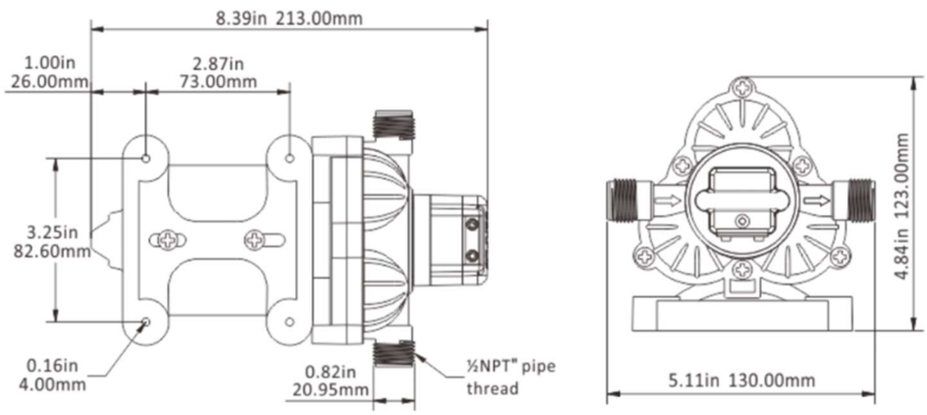

Figure 3 – Back and top view of the assembled diaphragm water pump

For each approach, a representative method to assess assembly complexity is considered. Implemented methods respectively were: Alkan's method; the entropy-based method proposed by Samy and ElMaraghy (2010) and the CXB assessment by Falck et al. (2017a).

3.1 Product-centered approach (Alkan, 2019)

As seen in (3), according to Alkan (2019) product complexity depends on three complexity coefficients:

- Component complexity $C_1 = \sum_{i=1}^{N} \alpha_i \approx \sum_{i=1}^{N} t_{handling,i}$, where α_i is the complexity of the i^{th} component approximated with the handling time of each single part (i.e., pick and place)

- Interface complexity $C_2 = \sum_{i=1}^{N} \sum_{j=1}^{N} \beta_{ij} A_{ij} \approx \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} t_{joining,ij} A_{ij}$, where β_{ij} is the complexity of each pair-wise connection calculated using time of joining, (i.e., positioning connectors and joining) and A is the product adjacency matrix defined as follows:

$$A_{ij} = \begin{cases} 1 & \text{if } i-th \text{ and } j-th \text{ part are directly connected} \\ 0 & \text{otherwise} \end{cases} \quad (5)$$

- Topological complexity $C_3 = \frac{E(A)}{N}$, where $E(A)$ is the energy of the product adjacency matrix A. According to graph theory, the energy of an adjacency matrix is defined as the sum of its absolute eigenvalues.

In order to compute the complexity of the water pump, average times of handling and joining tasks (Table 5) and the adjacency matrix of the product (Table 6) were computed.

The assembly operation was broken down in elementary tasks and their respective average times were measured. Average times (in seconds) were rounded up to the nearest integer.

Table 5 - Elementary tasks for the assembly of a diaphragm water pump

Elementary task	**Average time (s)**
Pick and place RF	2
Pick and place EB on RF	6
Screwing EB with RF	45
Insert F1 in F2	8
Pick and place D on F2	5
Screwing D and F1	66
Pick and place CV on D	6
Pick and place C on F2	5
Screwing C and F2	42
Insert R	8
Insert assembled pump head on EB	14
Screwing pump head and EB	45
Pick and place PSD	15
Pick and place PS	5
Screwing PS and C	48
Screwing F	6
Screwing FA1 and FA2	19

Table 6 - Adjacency matrix

A	RF	EB	R	F1	F2	D	CV	FI	C	PS	PSD	FA1	FA2
RF	0	1	0	0	0	0	0	0	0	0	0	0	0
EB	1	0	1	1	1	0	0	0	1	0	0	0	0
R	0	1	0	0	0	0	0	0	0	0	0	0	0
F1	0	1	0	0	1	1	0	0	0	0	0	0	0
F2	0	1	0	1	0	1	0	0	1	0	0	0	0
D	0	0	0	1	1	0	1	0	0	0	0	0	0
CV	0	0	0	0	0	1	0	0	0	0	0	0	0
FI	0	0	0	0	0	0	0	0	1	0	0	1	0
C	0	1	0	0	1	0	0	1	0	1	1	0	1
PS	0	0	0	0	0	0	0	0	1	0	1	0	0
PSD	0	0	0	0	0	0	0	0	1	1	0	0	0
FA1	0	0	0	0	0	0	0	1	0	0	0	0	0
FA2	0	0	0	0	0	0	0	0	1	0	0	0	0

The eigenvalues referring to the adjacency matrix are shown in Table 7.

Table 7 - Eigenvalues of the adjacency matrix

λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}	λ_{13}
-2,45	-1,99	-1,15	-1	-1	-0,61	0	0,21	0,33	1	1,21	2,07	3,38

The three contributes of complexity obtained respectively are:

$$C_1 = \sum_{i=1}^{n} t_{handling,i} = 44\ s \quad C_2 = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} t_{joining} A_{ij} = 301\ s \quad C_3 = \frac{\sum_{i=1}^{n} |\lambda|}{n} = 1{,}262$$

The overall complexity for the water pump is:

$$C = C_1 + C_2 C_3 = 424\ s = 7.07\ min$$

The overall domain of product complexity postulated by Alkan is $C \in]0; +\infty[$ as it is a measure of time expressed in seconds. Time is an easy measurable variable, thus avoiding any source of subjectivity in the implementation of the method. On the contrary, the difficulty to compute topological complexity may increase in the presence of products composed of many different parts connected.

To better understand the results obtained, Table 8 shows the maximum and minimum complexity values (in minutes) calculated in the study by Verna et al. (2021) concerning the assembly of a wrapping machine. In this work, the assembly process was divided into 29 workstations, each characterized by a specific number of components to assemble (n) and elementary operations to be performed.

Table 8 - Maximum and minimum complexity value for the assembly of a wrapping machine (Verna *et al.*, 2021)

Identification number of workstation	Number of elementary operations	n	C_1(min)	C_2(min)	C_3(min)	C(min)
9	2	4	0,08	0,33	0,25	0,16
28	9	20	1,26	11,32	0,60	8,05

The complexity values obtained for the assembly of a diaphragm water pump are shown in Table 9.

Table 9 - Complexity values of the assembly of a diaphragm water pump

Number of elementary operations	n	C_1(min)	C_2(min)	C_3(min)	C(min)
17	13	0.73	5,02	1,262	7,07

In this specific case the overall complexity value increases as the number of components increases. The number of elementary operations relatively affects the complexity value, since this mainly depends on the duration of each elementary operation. The topological complexity, on the other hand, has a strong impact on the overall value, reducing the distance between the complexity of the workstation 28 and that of the water pump.

3.2 Information-centered approach (Samy and ElMaraghy, 2010)

Samy and ElMaraghy (2010) proposed an information-based approach to evaluate complexity, combining information entropy with a coefficient derived from DFA principles (Boothroyd, 1994), as seen in (4).
The complexity factor defined by Samy and ElMaraghy is a dimensionless measure of complexity defined in $]0; +\infty[$ as it depends on number of parts and fasteners with $n_p, n_s, N_p, N_s \geq 1$.
In this practical case study DFA tables for manual assembly (Samy and ElMaraghy, 2010) were used for the computation of $CI_{product}$. The calculation of $CI_{product}$ was composed of the following steps:

- Calculation of average handling factor $C_h = \frac{\sum_1^J C_{h,f}}{J}$ and average insertion factor $C_i = \frac{\sum_1^K C_{i,f}}{K}$. The two previous parameters are estimated using complexity assembly factors obtained from DFA analysis (Samy and ElMaraghy, 2010). Experts choose J handling attributes and K insertion attributes applicable to the component under assessment and calculate a respective average value (i.e., C_h and C_i).

- Calculation of weighted average (handling and insertion) complexity factor

$$C_{part} = \frac{C_h \sum_1^J C_{h,f} + C_i \sum_1^K C_{i,f}}{\sum_1^j C_{h,f} + \sum_1^K C_{i,f}} \tag{6}$$

- Calculation of product complexity index $CI_{product} = \sum_{p=1}^{n} x_p C_{part}$ where x_p is the percentage of dissimilar parts and n the number of unique parts.

A team of experts evaluated handling and insertion attributes for this specific case study. The value obtained was $CI_{water\ pump} = 0{,}693$. Being $n_p = 12$, $N_p = 13, n_s = 4$ and $N_s = 14$, it resulted that:

$$C_{water\ pump} = 7{,}27$$

As a reference value, the complexity factor calculated by Samy and ElMaraghy (2010) for the assembly of an automobile engine piston is used. Such a product is composed of 11 parts ($N_p = 11, n_p = 8$) and 2 fasteners ($N_s = 2, n_s = 1$), $CI_{piston} = 0{,}83$ and so:

$$C_{piston} = 6{,}39$$

Samy and ElMaraghy's complexity index is mainly influenced by degree of variety of parts and fasteners. The assembly of the water pump is indeed more complex due to a greater quantity and diversity of components and fasteners. It should be noted, however, that $CI_{water\ pump} < CI_{piston}$, as this depends on the geometrical characteristics of each part and on the characteristics of the fastening process. A major weakness of this method, in fact, is that experts must provide an assessment on insertion and handling attributes. Although based on semi-quantitative criteria, CI value may be also influenced by expert judgements.

3.3 System-centered approach (Falck, A. et al., 2017)

Falck et al. proposed a tool to assess complexity of an assembly task based on expert assessments, namely CXB assessment (Falck, Tarrar, *et al.*, 2017; Falck, Örtengren, *et al.*, 2017a, 2017b). This method is composed of 16 high complexity (HC) criteria corresponding to 16 low complexity (LC) criteria, on which experts assess an assembly process. For each criterion also an interpretation aimed at helping experts in their judgements is provided (Falck, A. *et al.*, 2017a). The detailed set of statements is provided in Appendix A. The number of high complexity (or low complexity) criteria met can range between 0 and 16, determining the level of complexity of the assembly task, as shown in Table 10. The complexity of a task is expressed on a 5-level scale where level 1 indicates a low-complexity task while level 5 indicates a high-complexity task.

Table 10 – Fulfilment of high complexity criteria and corresponding complexity levels (Falck, Örtengren, *et al.*, 2017b)

Complexity level	Number of HC criteria fulfilled	Range
1	0-3	Low
2	4-7	Rather low
3	8-11	Moderate
4	12-14	Rather high
5	15-16	High

With reference to Table 11, the main tasks composing the assembly process of a water pump were identified. Average times include pick and place times of each part and related assembly time.

Table 11 - CXB assessment of a water pump assembly

Tasks	Average time	Number of HC criteria fulfilled	Range
Screwing EB and RF	53 s	1	Low
Screwing D and F1	79 s	8	Moderate
Screwing C and F2	53 s	5	Rather low
Screwing pump head and EB	67 s	5	Rather low
Screwing PS and C	68 s	5	Rather low
Screwing FI, FA1 and FA2	25 s	2	Low

Results showed that the assembly of diaphragm and flange 1 was the most critical. The strong influence of the subjective judgements of the experts is undoubtedly the main weakness of this method. Even though some guidelines to make an objective assessment are provided, assessments will be inevitably influenced by experts' experiences. One of the main contributes of this work is the attempt to include different dimensions that may affect the complexity of a task, without only focusing on product features.

4. ASSEMBLY COMPLEXITY IN COLLABORATIVE TASKS

The practical case study (section 3) shed more light on which are the main variables defining complexity in the three different approaches. The methods analyzed focused heavily on product and information-based complexity, neglecting interactions between agents that are also part of the assembly process, and thus potential cause of defects. In a collaborative assembly, this new dimension of interaction complexity becomes crucial. Malik and Bilberg (2019) identified three main causes for HRC complexity: parts, process and workspace. Regarding workspace, they considered HRC safety as the only variable influencing task complexity. Many other studies though, proved that human robot collaboration should be evaluated using also other dimensions, i.e., autonomy, information, team organization, adaptivity, task, human factors, ethics and cybersecurity (Gervasi *et al.*, 2020). A new vision of complexity in a collaborative assembly process is therefore proposed (Figure 4).

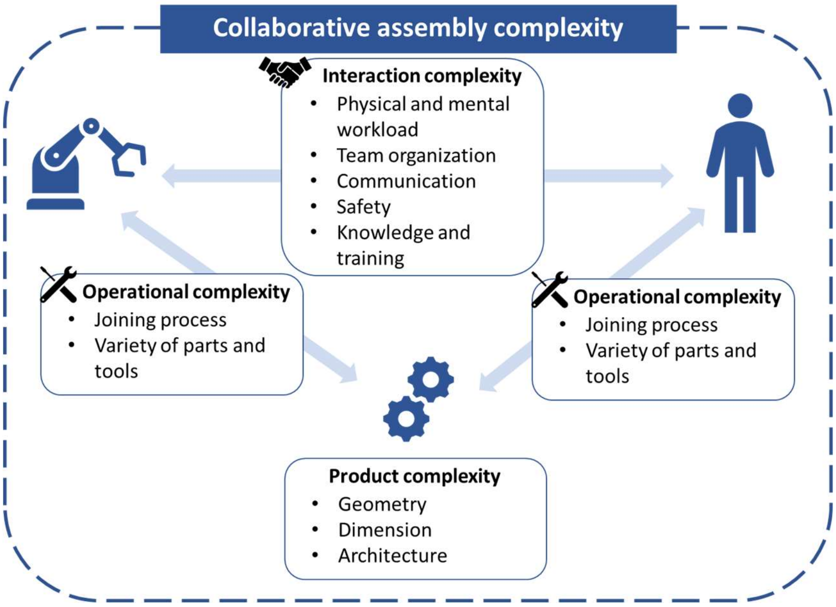

Figure 4 - Complexity framework for collaborative assembly

The complexity of an assembly process with collaborative robotics can be reduced to three main categories:

- Product complexity: it derives from intrinsic physical features of single parts (Malik and Bilberg, 2019). This type of complexity depends mainly on number of parts composing products, their architectures, geometrical and dimensional characteristics.
- Operational complexity: it is related to difficulties of assembly, such as insertion resistance, type of joining, etc. (Malik and Bilberg, 2019). In addition to these elements, sources of operational complexity may also include variety of product demanded and of tools needed.
- Interaction complexity: it includes all those variables that may influence an assembly task when it is carried out by several agents, i.e., humans and robots. Most studies in the field have only focused on safety as crucial variable (Malik and Bilberg, 2019), but in evaluating human robot collaboration a multidimensional approach should be followed.

While first two types of complexity were widely investigated across literature, assessing interaction complexity represents a new challenge in manufacturing control. Interaction complexity aims to describe the dynamics by which multiple agents interact with each other. When describing interaction complexity in an assembly process, all those variables that are typical of the interaction between multiple agents (e.g., human and robot) should be considered, as they may have an impact on the success of the process itself. To this purpose, the HRC evaluation framework proposed by Gervasi et al. (2020) was used to highlight main dimensions that may influence the complexity of interaction in an assembly process. Variables, such as communication, team organization, safety, mental workload, physical ergonomics and knowledge and training were considered crucial also in assessing manual assembly complexity, while cybersecurity, ethics, autonomy and adaptivity were specifically related to the introduction of cobots in production workstations and thus were neglected in this preliminary comparison. The main dimensions adapted from Gervasi et al. (2020) on which both manual and human-robot assembly could be assessed are as follows:

- Communication

  Communication is a crucial element in interaction between agents (Goodrich and Schultz, 2008). An appropriate and well-designed exchange of information influences success and efficiency of the task. Operators' awareness of procedures to be followed impacts positively on task performances, especially in terms of product and process defects.

- Team organization

  Team organization aims to assess the organization of agents involved in a task, focusing mainly on balance between members and their role in pursuing a specific goal. Roles of each agent must be well assigned in order to successfully complete the task (Goodrich and Schultz, 2008).

- Safety

  Safety in manufacturing processes has been extensively studied over the years. Many regulations have been introduced to quantify and reduce risks for workers in human-robot collaboration. From this perspective, it can be assumed that the riskiness of HRC operations is directly related to their complexity (Malik and Bilberg, 2019).

- Mental workload

  Mental workload refers to the mental effort of operators during the execution of a task. Complex and stressful actions may generate fatigue and alienation. This condition of mental distress can affect performances and subsequently the quality of outputs and processes (Arai *et al.*, 2010).

- Physical ergonomics

  Physical ergonomics encompasses all those measures taken to ensure that worker movements and postures are safe and correct. The amount of physical effort required impacts on the complexity of the assembly activity, leading to a deterioration in product and process quality due to exhausting and alienating actions (Zare *et al.*, 2016).

- Knowledge and training

In a successful human-robot collaboration, the skills of the operators and the related training required to interface with the robot are critical (Gervasi et al., 2020). Even in a manual assembly, however, the level of knowledge and experience of the operators involved has an impact on the complexity and success of the assembly process.

Complexity assessment methods were analyzed with a view to their future possible implementation in collaborative assembly. Tables 12, 13 and 14 show, for each approach, the methods obtained through literature review and their coverage of HRC typical dimensions. Some interesting results emerge from the analysis:

- Product-centered methods mainly focus on defining objective parameters that consider the architecture of products and the corresponding time required to handle them. The physical characteristics of the components and the corresponding product architecture, however, remains a key aspect in the complexity assessment, since the geometry of the components influences task complexity, even in a collaborative task. On the other hand, the assumption that cycle time is the only measure of task complexity in a collaborative approach loses some of its significance. In fact, the cycle time in a human-robot task is influenced both by the design of the task itself and by the technological and safety limits of the machine. These methods are obviously the least suitable for evaluating collaborative assemblies as they fail to cover any of the dimensions needed to assess human-machine interaction.

Table 12 -HRC Complexity vs product-centered approaches in literature. The table highlights HRC dimensions covered or not covered by the models

HRC assembly complexity										
		Task		Interaction						
Year	Authors	Product	Operational	Communication	Team organization	Safety	Mental Workload	Physical ergonomics	Knowledge and training
1993	Hinckley M.	x	x						
1994	Ben-Arieh, D.	x	x						
2002	Shibata, H.	x	x						
2010	Su Q., et al.	x	x						
2012	Mathieson J.L., et al.	x	x						
2014	Sinha, K.	x							
2017	Alkan B., et al.	x	x						
2018	Genta et al.	x	x						
2019	Alkan B.	x	x						
2021	Verna et al.	x	x						

- Information-centered approach begins to shift the focus to the operator. Methods belonging to this approach assume that the complexity of a task depends on the variety of choices an operator is led to make. A greater variety of components, of tools to be used, of different assembly sequences increase the complexity of the assembly task. The operator is forced to choose between various configurations, and this generates more mental effort. It is worth noting that the amount of information an operator manages in a collaborative task may be partially mitigated by the presence of a robot. It is possible to design the task in such a way that the robot provides the parts to the operator in the order in which they are to be assembled, thus considerably reducing the choices left to the human operator. From this perspective, it can be stated that methods belonging to this approach are more suitable to be adapted for the assessment of a collaborative assembly task, since they also investigate mental load. However, many other fundamental dimensions in collaborative interaction complexity remain uncovered.

Table 13 – HRC complexity vs information-centered approaches in the literature. The table highlights HRC dimensions covered or not covered by the models

HRC assembly complexity									
		Task		**Interaction**					
Year	**Authors**	**Product**	**Operational**	**Communication**	**Team organization**	**Safety**	**Mental Workload**	**Physical ergonomics**	**Knowledge and training**
2003	ElMaraghy W.H. and Urbanic R.J.	x	x						
2003	Fujimoto H., et al.	x	x						
2004	ElMaraghy W.H. and Urbanic R.J.	x	x				x	x	
2008	Ameri F., et al.	x	x						
2008	Zhu X., et al.	x	x				x		
2010	Samy S.N. and ElMaraghy H.	x	x						
2010	Wang H. and Hu S.J.	x	x				x		
2012	Samy S.N. and Elmaraghy H.A.	x	x				x		
2013	Wang H., et al.		x						
2014	Modrak V., et al.	x	x						
2015	Park K. and Okudan Kremer G.E.	x	x						

- Methods that attempt to capture system complexity seem to be best suited to describe interaction complexity as well. The main strength of methods belonging to this approach is that they share a multidimensional view of complexity. Unlike the previous two approaches, however, they do not always succeed in defining an objective and quantifiable measure of complexity due to the large number of variables to be considered. Some of them rely heavily on questionnaires and expert judgements which, while providing a holistic view of the problem, also introduce subjectivity in expert assessments.

Table 14 - HRC complexity vs system-centered approaches in the literature. The table highlights HRC dimensions covered or not covered by the models

HRC assembly complexity									
		Task		Interaction					
Year	Authors	Product	Operational	Communication	Team organization	Safety	Workload	Physical ergonomics	Knowledge and training
2009	Zaeh M.F., et al.	x	x				x	x	x
2010	Jenab K. and Liu D.	x	x		x				x
2011	Abad A.G. and Jin J.	x	x	x					
2012	Samy S.N. and ElMaraghy H.	x	x						
2013	Al-Zuheri A.	x	x				x	x	x
2013	Chryssolouris G., et al.	x	x						
2014	Elmaraghy H., et al.	x	x						
2016	Mattsson S., et al.	x	x		x	x	x	x	x
2017	Falck A.-C., et al.	x	x			x	x	x	x
2018	Modrak V. and Soltysova Z.	x	x						
2019	Busogi M., et al.	x	x					x	
2020	Martínez-Olvera C.	x	x						

5. CONCLUSIONS

In this preliminary investigation, the aim was to identify the most suitable approach for the assessment of assembly complexity in collaborative tasks, starting from the methods available in the literature. Unlike manual assembly, in a collaborative task the co-presence of humans and robots and the simultaneity of their actions can generate a significant impact on the operator's well-being, thus influencing the quality of the interaction. In this context, the approach considered most suitable for modelling complexity in collaborative assembly is the system-centered approach, as it tends to provide a holistic view of complexity. None of these methods, however, directly introduces multi-agent interaction as a variable that can influence the complexity of an assembly process. Despite its exploratory nature, this study offers some insights into the definition of a new concept of complexity for collaborative assembly, which cannot focus only on the product, but also on the complexity of interaction among the agents involved. Future developments will involve the analysis of the relationship between interaction complexity and observable defects in collaborative tasks and thus their contextual effects on product and process quality.

6. REFERENCES

Abad, A. and Jin, J. (2011), “Complexity metrics for mixed model manufacturing systems based on information entropy”, *International Journal of Information and Decision Sciences*, Vol. 3, pp. 313–334.

Alkan, B. (2019), “An experimental investigation on the relationship between perceived assembly complexity and product design complexity”, *International Journal on Interactive Design and Manufacturing (IJIDeM)*, Springer Science and Business Media LLC, Vol. 13 No. 3, pp. 1145–1157.

Alkan, B., Vera, D., Ahmad, B. and Harrison, R. (2018), “A Method to Assess Assembly Complexity of Industrial Products in Early Design Phase”, *IEEE Access*, presented at the IEEE Access, Vol. 6, pp. 989–999.

Alkan, B., Vera, D.A., Ahmad, M., Ahmad, B. and Harrison, R. (2018), “Complexity in manufacturing systems and its measures: A literature review”, *European Journal of Industrial Engineering*, Vol. 12 No. 1, pp. 116–150.

Al-Zuheri, A. (2013), “Structural and operational complexity of manual assembly systems”, *Journal of Computer Science*, Vol. 9, pp. 1822–1829.

Ameri, F., Summers, J., Mocko, G. and Porter, M. (2008), “Engineering design complexity: An investigation of methods and measures”, *Research in Engineering Design*, Vol. 19, pp. 161–179.

Arai, T., Kato, R. and Fujita, M. (2010), “Assessment of operator stress induced by robot collaboration in assembly”, *CIRP Annals*, Vol. 59 No. 1, pp. 5–8.

Bauer, A., Wollherr, D. and Buss, M. (2008), “Human–robot collaboration: a survey”, *International Journal of Humanoid Robotics*, World Scientific Publishing Co., Vol. 05 No. 01, pp. 47–66.

Ben-Arieh, D. (1994), “A methodology for analysis of assembly operations’ difficulty”, *International Journal of Production Research*, Taylor & Francis, Vol. 32 No. 8, pp. 1879–1895.

Boothroyd, G. (1994), “Product design for manufacture and assembly”, *Computer-Aided Design*, Vol. 26 No. 7, pp. 505–520.

Busogi, M., Song, D., Kang, S.H. and Kim, N. (2019), “Sequence Based Optimization of Manufacturing Complexity in a Mixed Model Assembly Line”, *IEEE Access*, presented at the IEEE Access, Vol. 7, pp. 22096–22106.

Chryssolouris, G., Efthymiou, K., Papakostas, N., Mourtzis, D. and Pagoropoulos, A. (2013), “Flexibility and complexity: is it a trade-off?”, *International Journal of Production Research*, Taylor & Francis, Vol. 51 No. 23–24, pp. 6788–6802.

ElMaraghy, W.H. and Urbanic, R.J. (2004), “Assessment of Manufacturing Operational Complexity”, *CIRP Annals*, Vol. 53 No. 1, pp. 401–406.

ElMaraghy, H., AlGeddawy, T., Samy, S.N. and Espinoza, V. (2014), “A model for assessing the layout structural complexity of manufacturing systems”, *Journal of Manufacturing Systems*, Vol. 33 No. 1, pp. 51–64.

ElMaraghy, W.H. and Urbanic, R.J. (2003), “Modelling of Manufacturing Systems Complexity”, *CIRP Annals*, Vol. 52 No. 1, pp. 363–366.

Falck, A.-C., Örtengren, R., Rosenqvist, M. and Söderberg, R. (2017a), “Proactive assessment of basic complexity in manual assembly: development of a tool to predict and control operator-induced quality errors”, *International Journal of Production Research*, Taylor & Francis, Vol. 55 No. 15, pp. 4248–4260.

Falck, A.-C., Örtengren, R., Rosenqvist, M. and Söderberg, R. (2017b), “Basic complexity criteria and their impact on manual assembly quality in actual production”, *International Journal of Industrial Ergonomics*, Vol. 58, pp. 117–128.

Falck, A.-C., Tarrar, M., Mattsson, S., Andersson, L., Rosenqvist, M. and Söderberg, R. (2017), “Assessment of manual assembly complexity: a theoretical and empirical comparison of two methods”, *International Journal of Production Research*, Taylor & Francis, Vol. 55 No. 24, pp. 7237–7250.

Fujimoto, H., Ahmed, A., Iida, Y. and Hanai, M. (2003), “Assembly Process Design for Managing Manufacturing Complexities Because of Product Varieties”, *International Journal of Flexible Manufacturing Systems*, Vol. 15 No. 4, pp. 283–307.

Genta, G., Galetto, M. and Franceschini, F. (2018), “Product complexity and design of inspection strategies for assembly manufacturing processes”, *International Journal of Production Research*, Taylor & Francis, Vol. 56 No. 11, pp. 4056–4066.

Gervasi, R., Mastrogiacomo, L. and Franceschini, F. (2020), “A conceptual framework to evaluate human-robot collaboration”, *The International Journal of Advanced Manufacturing Technology*, Vol. 108 No. 3, pp. 841–865.

Goodrich, M.A. and Schultz, A.C. (2008), “Human–Robot Interaction: A Survey”, *Foundations and Trends® in Human–Computer Interaction*, Now Publishers, Inc., Vol. 1 No. 3, pp. 203–275.

Hinckley, C.M. (1994), *A Global Conformance Quality Model. A New Strategic Tool for Minimizing Defects Caused by Variation, Error, and Complexity*, No. SAND-94-8451, Sandia National Lab. (SNL-CA), Livermore, CA (United States), available at:https://doi.org/10.2172/10120374.

Jenab, K. and Liu, D. (2010), “A graph-based model for manufacturing complexity”, *International Journal of Production Research*, Taylor & Francis, Vol. 48 No. 11, pp. 3383–3392.

Malik, A.A. and Bilberg, A. (2019), “Complexity-based task allocation in human-robot collaborative assembly”, *Industrial Robot: The International Journal of Robotics Research and Application*, Emerald Publishing Limited, Vol. 46 No. 4, pp. 471–480.

Martinez Olvera, C. (2020), "An Entropy-Based Formulation for Assessing the Complexity Level of a Mass Customization Industry 4.0 Environment", *Mathematical Problems in Engineering*, Vol. 2020, pp. 1–19.

Mathieson, J.L., Wallace, B.A. and Summers, J.D. (2013), "Assembly time modelling through connective complexity metrics", *International Journal of Computer Integrated Manufacturing*, Taylor & Francis, Vol. 26 No. 10, pp. 955–967.

Mattsson, S., Karlsson, M., Gullander, P., Landeghem, H.V., Zeltzer, L., Limère, V., Aghezzaf, E., *et al.* (2014), "Comparing quantifiable methods to measure complexity in assembly", *Int. J. Manuf. Res.*, available at:https://doi.org/10.1504/IJMR.2014.059602.

Mattsson, S., Tarrar, M. and Fast-Berglund, Å. (2016), "Perceived production complexity – understanding more than parts of a system", *International Journal of Production Research*, Taylor & Francis, Vol. 54 No. 20, pp. 6008–6016.

Mattsson, S., Tarrar, M. and Harari, N. (2020), "Using the compleXity index for improvement work: investigating utilisation in an automotive company", *International Journal of Manufacturing Research*, Vol. 15, p. 3.

Mital, A. and Pennathur, A. (2004), "Advanced technologies and humans in manufacturing workplaces: an interdependent relationship", *International Journal of Industrial Ergonomics*, Vol. 33 No. 4, pp. 295–313.

Modrak, V., Marton, D. and Bednar, S. (2014), "The Impact of Customized Variety on Configuration Complexity of Assembly Process", *Applied Mechanics and Materials*, Vol. 474, pp. 135–140.

Modrak, V. and Soltysova, Z. (2018), "Development of operational complexity measure for selection of optimal layout design alternative", *International Journal of Production Research*, Taylor & Francis, Vol. 56 No. 24, pp. 7280–7295.

Oztemel, E. and Gursev, S. (2020), "Literature review of Industry 4.0 and related technologies", *Journal of Intelligent Manufacturing*, Vol. 31 No. 1, pp. 127–182.

Park, K. and Okudan Kremer, G.E. (2015), "Assessment of static complexity in design and manufacturing of a product family and its impact on manufacturing performance", *International Journal of Production Economics*, Vol. 169, pp. 215–232.

Samy, S.N. and ElMaraghy, H. (2010), "A model for measuring products assembly complexity", *International Journal of Computer Integrated Manufacturing*, Taylor & Francis, Vol. 23 No. 11, pp. 1015–1027.

Samy, S.N. and ElMaraghy, H. (2012), "A model for measuring complexity of automated and hybrid assembly systems", *The International Journal of Advanced Manufacturing Technology*, Vol. 62 No. 5, pp. 813–833.

Shannon, C.E. (1948), “A mathematical theory of communication”, *The Bell System Technical Journal*, presented at the The Bell System Technical Journal, Vol. 27 No. 4, pp. 623–656.

Shibata, H. (2002), *Global assembly quality methodology: A new method for evaluating assembly complexities in globally distributed manufacturing*, Ph.D., Ann Arbor, United States, June, available at: https://www.proquest.com/docview/305543109/abstract/811A6D971B8542CDPQ/1 (accessed 12 February 2022).

Simpson, T.W. and D’Souza, B.S. (2004), “Assessing Variable Levels of Platform Commonality Within a Product Family Using a Multiobjective Genetic Algorithm”, *Concurrent Engineering*, SAGE Publications Ltd STM, Vol. 12 No. 2, pp. 119–129.

Sinha, K. (2014), *Structural Complexity and Its Implications for Design of Cyber-Physical Systems*, Thesis, Massachusetts Institute of Technology, available at: https://dspace.mit.edu/handle/1721.1/89871 (accessed 14 February 2022).

Sinha, K. and de Weck, O.L. (2014), “Structural Complexity Quantification for Engineered Complex Systems and Implications on System Architecture and Design”, presented at the ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, American Society of Mechanical Engineers Digital Collection, available at:https://doi.org/10.1115/DETC2013-12013.

Su, Q., Liu, L. and Whitney, D.E. (2009), “A Systematic Study of the Prediction Model for Operator-Induced Assembly Defects Based on Assembly Complexity Factors”, *IEEE*, Institute of Electrical and Electronics Engineers, available at: https://dspace.mit.edu/handle/1721.1/53551 (accessed 12 February 2022).

Verna, E., Genta, G., Galetto, M. and Franceschini, F. (2021), “Defects-per-unit control chart for assembled products based on defect prediction models”, *The International Journal of Advanced Manufacturing Technology*, available at:https://doi.org/10.1007/s00170-021-08157-1.

Wang, H. and Hu, S.J. (2010), “Manufacturing complexity in assembly systems with hybrid configurations and its impact on throughput”, *CIRP Annals*, Vol. 59 No. 1, pp. 53–56.

Wang, H., Wang, H. and Hu, S.J. (2013), “Utilizing variant differentiation to mitigate manufacturing complexity in mixed-model assembly systems”, *Journal of Manufacturing Systems*, Vol. 4 No. 32, pp. 731–740.

Xu, L.D., Xu, E.L. and Li, L. (2018), “Industry 4.0: state of the art and future trends”, *International Journal of Production Research*, Taylor & Francis, Vol. 56 No. 8, pp. 2941–2962.

Zaeh, M.F., Wiesbeck, M., Stork, S. and Schubö, A. (2009), “A multi-dimensional measure for determining the complexity of manual assembly operations”, *Production Engineering*, Vol. 3 No. 4, p. 489.

Zare, M., Croq, M., Hossein-Arabi, F., Brunet, R. and Roquelaure, Y. (2016), “Does Ergonomics Improve Product Quality and Reduce Costs? A Review Article”, *Human Factors and Ergonomics in Manufacturing & Service Industries*, Vol. 26 No. 2, pp. 205–223.

Zhu, X., Hu, S.J., Koren, Y. and Marin, S.P. (2008), “Modeling of Manufacturing Complexity in Mixed-Model Assembly Lines”, *Journal of Manufacturing Science and Engineering*, Vol. 130 No. 5, available at:https://doi.org/10.1115/1.2953076.

APPENDIX A: High and low complexity criteria (Falck, A. et al., 2017)

n	High complexity criteria	Low complexity criteria
1	Many different ways of doing the task	Standardized way to do the task
2	Many individual details and parts operations	Few details to mount; pre-assembly; module solution
3	Time demanding operations	Solution that are easy and quick to assemble
4	No clear mounting position of parts and components	Clear mounting position of parts and components
5	Poor accessibility	Good accessibility
6	Hidden operations	Visible operations
7	Poor ergonomics conditions implying risk of harmful impact on operator	Good ergonomics conditions implying no harmful impact on operators
8	Operator dependent task requiring expert knowledge to be properly done	Non operator dependent operations not requiring much experience to be properly done
9	Operations must be done in a certain order/sequence	Independence of assembly order
10	Visual inspection of fitting and tolerance is required, i.e., careful subjective assessment of the quality output	Standardized assembly. Careful subjective assessment of fitting/tolerances is not needed
11	Accuracy/precision demanding task	No precision-demanding task, no careful fitting is necessary
12	Need of adjustment	No adjustment needed
13	The geometric environment has a lot of variation (“tolerances”) meaning the level of fitting and adjustment varies between the products	Easy fitting, self-positioning parts/components that can be controlled in 3 dimensions x,y, and z
14	Need to have in detail described work instructions	Self-evident operations that do not need clearly written instructions
15	Soft and flexible material	Form resistant material that does not change shape or form during assembly
16	Lack of immediate feedback of properly done work, e.g., by a clear click sound and/or compliance with reference point	Immediate feedback of proper installation e.g., by a clear click sound and/or compliance with reference points

User-Generated content mining: Exploring paths on the Quality perspective

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ABSTRACT

The user-generated content are all the publications made available by online users in platforms. They can offer advantages to the companies because they can obtain feedback directly from the customers and improve specification attributes of the product or service features. Hereupon, since demands for reliable service, delivery and short answering times significantly increased, there is an enormous need for improvement in the quality of the products and services provided.

One can define quality, as being the service characteristics, which correspond exactly to what customers need, require and expect, *i.e.*, the attention given to the specification conformity, what makes the company to adopt different approaches to obtain information with direct contact with the customer. Considering that the digital platform encompasses the daily communication between customers and companies, it is important to analyse the user-generated content, such as comments, suggestions, ratings, criticism, especially in the tourism and hospitality industry (the majority of evaluation platforms).

The specific goals of this research, consist in analysing and studying the data obtained from the digital platform "Booking", where the customers hold the possibility to evaluate the services provided, with comments, to reveal important information in the field of quality, and how that information can be used to improve the performance and the decisions made by the company to obtain competitive advantage.

To reach the proposed goals, a bibliographic analysis was carried out in which it was possible to analyse the maximum information, that exist about this topic.

Keywords: User-Generated Content, Quality, Text Mining, Booking.

1. INTRODUCTION

The main goal of companies should be to improve the quality of their products, services, and customer satisfaction so that, they become loyal, because when they enjoy the products and the services they will judge and dictate the level of their quality.

In recent years, an evolution of Information and Communication Technologies was observed, allowed to access the internet through several devices and a great facility in communication. At the same time, there was a transformation in human behaviour on the internet, beyond being a consumer, it is also an active creator of contents through various digital platforms (Shirky, 2010).

Technological development and the increase in Internet access have allowed people to be more connected with each other. The information provided by users, where they freely expose their criticisms, on digital platforms, generates information of great value, which reflects the user's perception of their experiences in relation to the services and products they have enjoyed.

The feedback given by customers on digital platforms is still a recent parameter and lowly valued by companies, however it can be used to assess the quality and attributes of services, which influence customer (dis)satisfaction.

Therefore, it is important to know whether or not these digital platforms can be used as a quality management tool by companies, more specifically hotels and restaurants.

That said, the focus of the research is to explore, from a quality perspective, the prospecting of user-generated content and to relate hypothesis tests with textual analysis of comments made online, to see if there is important information for companies.

Initially, a bibliographic review research was carried on, in order to analyse as much information as possible on the subject and with the help of this, a concrete and objective analysis was carried on the data found on platforms available online, where indicators of content analysis and hypothesis testing, to detect current trends and patterns in online assessments, in order to achieve the proposed objectives.

2. BIBLIOGRAPHIC REVIEW

2.1. Quality

There is already a concern on the part of companies, with quality, since the beginning of the 20th century, but "the various ways in which companies plan, define, obtain, control, continually improve and demonstrate quality, have suffered great developments over recent times, responding to political, economic and social changes" (Mendes, 2007, p. 12).

However, it was only in the era of Quality Assurance that new concepts of quality emerged, which go hand in hand with developing and implementing activities in order to guarantee customer satisfaction (Pereira & Requeijo, 2008). The concepts and reflections, hitherto used by managers to pay attention to customers and establish long-term relationships, did not appear to be effective. Until the beginning of the 70s, when quality management emerged throughout the organization, prevention and planning began to encompass all processes throughout management, leading to an internal cooperation system that allowed the provision of products and services that satisfy the needs of customers. Quality was considered as an opening to be superior and better than the competition (Neto, 2009).

The concept of quality is quite complex, and it is important to understand what it really means and which its characteristics are. However, there are many interpretations, and each author gives more or less importance to certain aspects, and some definitions can complement each other.

For Deming (2000), quality is compliance with technical specifications and continuous commitment by top management, at the same time meeting market needs. Juran (1951) defines quality as the satisfaction of customer needs. Feigenbaun (1961) says that quality is the total of characteristics of a product or service that, when in use, will satisfy customer expectations. It is based on communication and improvement between departments of the organization, so that all members reach the common objective, which is to meet customer expectations. Finally, Crosby (1979) defines quality as compliance with customer requirements (requirements, specifications...) and defends products/services without defects.

There are numerous definitions of quality, but we can highlight two definitions by Juran (2002), which, are of highest importance for companies: the attributes of products/services and the absence of imperfections.

In this investigation, the most appropriate view is Juran's, because it is possible to evaluate the services performance at various points. However, the most important thing is to satisfy the needs of customers.

2.1.1. Service Quality

In this subchapter it is appropriate to define quality, with the view of Kotler (Sant'anna; Haddad, 2014): "quality is the set of attributes and characteristics of a product or service, capable of satisfying customer needs, whether implicit or declared".

Briefly, we can say that the evaluation of services is only done after the services are provided. However, in services, there are observable parts: environment, people interaction and also customers; and the non-visible part, which includes the organizations internal systems (procedures and processes), which generate a product that reach's people's needs. (Lovelock & Wirtz, 2006).

Products and services can be differentiated, products are produced, sold and only after that consumed; in services, however, they are sold first, only then produced and finally consumed. For example, when a hotel booked, before taking advantage of the offered service, its provided personal data and payment method. This is a part of the production processes (Zeithaml & Bitner, 1996).

Services are provided by people and, therefore, are not usually standardized or provided equally, because different people have different attitudes (Saias, 2007, p. 20). For example, when a person needs something, during the period in which he is at the hotel, he will ask to an employee, and that employee may be unwell on that day and provide poor service, leading to customer dissatisfaction with the service. However, on other days he can be an excellent professional. That services have their singularities and, therefore, need more dedication to make the quality consistent.

Currently, the issues of reliable service quality, delivery and short response times have increased significantly, which should led for high levels of quality in products and services.

It is difficult to define quality, because each client is different, unique and has a personal and subjective vision (González, Gândara, & Brea, 2006).

Customer satisfaction and quality are connected, even though they are different concepts (Spreng & Mackoy, 1996), because satisfaction can be momentary or temporary and the quality of a service, in turn, is the result of a general evaluation of performance (Spreng & Mackoy, 1996). Bateson & Hoffman, 2015). However, it is believed that the success of a company is linked to customer satisfaction (Dean & Bowen, 1994) and many authors support the idea that customer satisfaction is a result of the service quality (Taylor & Baker, 1994).

Berry & Parasuraman (1995, p. 75), "customers are the only judges of the service quality. Management may think the company's service is great, but when customers disagree with that idea, there's a problem."

In order to achieve excellence in service provision, according to Frei (2008), it is necessary for the company to be able to identify the characteristics of the service, where it has a lower performance and to compensate these characteristics with others, which have a superior performance and with more value for the customer.

So, the most important for companies is to focus on trying to understand which service attributes customers value most, the needs customers most want to see satisfied, and also the experiences they prioritize.

2.1.2. Tree Diagram and Pareto Diagram

Throughout the bibliographic research, it was possible to perceive that the tree diagram and the Pareto diagram can be applied in the investigation, tree diagram in Japan is one of the seven quality tools, being an accessible tool, which presents good results in relation to other tools (Oribe, 2012). It is a tool that analyses the causes of problems by breaking down problems, processes, tasks, etc. Typically, the tree diagram is more used to make problems that are difficult to solve, become simpler and easier to solve. Therefore, it is important to understand how and if this tool can help in this investigation.

To build a tree diagram the problem should exposed and then ask why this problem occurs, later the answers are noted, and each problem was originated from another problem. This is done successively, in order to get to the cause of the problems.

Therefore, for Paladini (2004):

"The tree diagram is a strategy to a direct planning towards specific targets, in the form of general objectives (what you want to achieve) and specific objectives (intermediate goals)." Briefly, the tree diagram can be used to identify in detail all the means and tasks necessary to achieve proposed objectives. However, to identify the problems with the greatest impact, the Pareto diagram can be used. The Pareto diagram is a quality tool, which consists of a graph of vertical bars, which allows you to visualize information clearly, and to establish specific goals (Werkema, 2006).

The Pareto Diagram allows you to visualize the problems mentioned by customers in a particular product/service. It is a tool that orders the frequencies of failures, making it possible to prioritize them. If a company has 10 problems and solves 2 of those problems, it can result in an 80% solution of the losses. (Carpinetti, 2010).

Mariano (2021) says that for the elaboration of the Pareto Diagram the following steps are necessary:

- Record problems to sort by priority.
- Analyse and compare.
- Analyse the process.
- Gather all the data collected to see the relationship between frequency and cost of each issue.
- Align problems on the graph from largest to smallest.

The Pareto Diagram is an efficient quality tool, which estimates the magnitude of problems, however, this diagram does not find the relationship between the cause and effects of the problems. It is necessary to use the tree diagram.

2.2. Digital Platforms

As previously seen, there is a need for customer-based information, which leads companies to adopt customer-involved information gathering approaches (Finch, 1999). Digital platforms are part of the daily communication between customers and companies (He, Zha & Li, 2013). This change in online communication also forced companies to change their vision towards a more dynamic and complex system (Lagrosen & Grundén, 2014). Customers who are part of the online interaction allow companies to obtain relevant information about profiles, preferences, experiences, and their expectations (Xiang et al, 2017). Online customer reviews (Chatterjee, 2001) have a greater influence on customer behaviour than traditional advertising (Yang & Mai, 2010), so it is important to analysing user-generated content, particularly in the tourism and hospitality industry, which is where there are more review platforms. Research has revealed that online customer reviews play an important role in influencing service performance in the hospitality industry (Cheng & Loi, 2014).

Digital platforms are defined by the European Commission as a companies that operates in the market through the internet and allow the interaction between several different users. Digital Platforms encompass services, social networks, search tools, video sharing and payment services. Therefore, this data allows to improve algorithms, products and services, etc. Companies are able to obtain vast amounts of data and personal opinions from consumers.

Digital platforms connect users/consumers to the seller, where they store all the information, so that it is possible to trace profiles of each user. This collected information serves as input (ideas that enter the process to help) in the production of goods and services that allow them to improve their quality, providing the consumer/user with products and services of their interest, maximizing the companies profits. Data can also be used to make strategic decisions, such as pricing. As more data collected, as the great is going to be the competitive advantage.

The analysis of digital platforms is related to the analysis of structured and unstructured data, which includes a variety of online platforms that allow users to create and exchange content. Digital platforms can be social networks, blogs, Wikis, question-and-answer sites and, finally, review sites such as Booking and TripAdvisor (Barbier & Liu, 2011; Gundecha & Liu, 2012).

The identification of information relevant to quality is based on the analysis of these data.

2.3. User-Generated content (UGC)

Internet users can play different roles in sharing content: there are users who do not interact, those who interact and those who produce personal content and share it on the internet (Shao, 2009).

The UGC, content posted by users, in any digital platform, can be any form of content such as text, images, videos, etc. Customers usually make comments, suggestions or criticisms independently. UGC is a content produced and shared on the internet by non-professional and unpaid personnel (Daugherty, Eastin, & Bright, 2008).

However, the UCG is increasingly important (Ayeh et al., 2013; Bilgihan et al., 2016), as it reveals information about products and services (Park, Lee, & Han, 2007).

The UGC allows companies to have information about consumers and have opportunities to make better decisions (Bilgihan, 2016; Fader & Winer, 2012; Filieri & Mcleay, 2014). The UGC is reliable and advantageous, because users trust opinions given by other consumers more than advertisements (Hassan, Nadzim, & Shiratuddin, 2015; Richard &

Guppy, 2014), as personal reports are not manipulated for people and lead them to purchase a service or product (Bickart & Schindler, 2001).

A positive or negative experience can lead the user to create content and convince or discourage customers or future customers from purchasing a certain service or product (Kimes, 2008). Digital platforms allow users to share experiences (Moore & Lafreniere, 2020) and, in competitive industries, taking advantage of this information can be a very important asset for companies to differentiate themselves from others (Rezvani & Safahani, 2016).

Thus, user evaluations reveal which attributes ensure the quality of services and products. Products and services with negative online reviews, even if they are offered in lower prices, are being eliminated by the competition that have more positive reviews, because the influence of online reviews is increasingly influencing consumer choice decisions. (Phillips, Barne, Zigan & Schegg, 2017).

2.4. Content analysis

User comments are in text format, so it's important to understand content analysis. Berelson in the late 1940s-1950s defines content analysis as an investigation technique that aims impartially, systematically and quantitatively produced by communication.

In a quantitative analysis, the frequency which certain characteristics of the content appear in the information is removed. In a qualitative analysis, what is important is the absence or presence of certain characteristics of the content, in a set of messages (George, 1959).

Content analysis is the combination of several analysis techniques to analyse a very broad field: communication. However, the researchers' objective, even using very different analysis procedures, will analyse:

- Inference of knowledge regarding the context of production or reception (may use quantitative indicators or not);
- Consideration of the meaning of the content (formal indices and analysis of co-occurrences);
- Seek to know the true meaning, in relation to the words used;
- The information needs to be treated before being understood, so that a descriptive and explanatory analysis of the content is possible.

For Bardin (1977), initially, to make a study of a text it is necessary:

- Conventions, which consists of the total number of words present or "occurrences" and the total number of different words that represent the vocabulary used by the users;
- Occurrence relations with vocabulary (O/V), studies the richness/poverty of the vocabulary used by the user, as it shows the average number of repetitions per vocabulary in the text;
- A qualitative analysis of words by order of frequency;
- Comparison of the characteristics of some speeches with others.

For raw results to be meaningful and valid, they need to be treated from simple statistical operations, such as percentages, allowing the identification of tables, diagrams, etc. (Bardin, 1977).

It is possible to establish a list of references within a set of texts and Bardin says that it is possible to use different types of enumerations:

- The presence or absence: the elements that are present can be signified, that is, they can be an indicator. However, the absence of certain elements can make some sense, which means that it is an important variable;
- Frequency: usually the most used measure. The frequency of the appearance of a unit increases the importance of a recording unit. A measure of frequency in which the appearances of the units all have the same weight, leading to all the elements having the same importance and this is not always the case;
- Weighted frequency: when it is assumed that the appearance of certain units is more important than others, it is necessary to use a weighting system;
- Direction: it can be favorable, unfavorable or neutral, it reflects a qualitative character.

Using the computer in some situations is interesting Holsti (1969):

- Analyse the unit, the number of times the word occurs (frequency indicator);
- Complex analysis, where there are many variables to analyse at the same time (many categories);
- Analysis of co-occurrences (when two or more recording units appear together);

- The investigation goes through several analyses, and the computer makes it possible to prepare the data and store it for various uses;
- Complex statistical and numerical operations.

The use of a computer in content analysis makes it possible to speed up the analysis and there is an increase in rigor of the organization, because the computer does not allow for ambiguity, that is, it is necessary to clarify each step of the investigation.
Bardin (1997) says that nowadays, anyone who has a personal computer can explore word processing programs that are available on the market. These programs allow: cutting sentences or sequences, searching for certain words, counting the frequency, analysing the average length of sentences, organizing by topic and sorting in tree schemes.
Briefly, it is usual to use the word as a counting unit and the computer allows creating an alphabetical list of all the existing words in the text, after that it is possible to calculate the frequency and occurrence of the words, to understand which words are most and least used, which may eventually allow us to see if it has any significant value in the analysis. However, some high frequency words like “the”, “of”, “to”, etc., have little lexical meaning and the computer allows you to ignore these terms, however it is also possible to ignore some low frequency or rare words, which have significant value. It is also possible to find co-occurrence between words, that is, to isolate a given word and combine it with immediate words.
However, quantitative analysis based on word frequency has led to other content analysis measures. Quantitative analysis is not very intuitive and systematic because it defines the parameters used. However, it was necessary to approach in a different and comparative way, which led to the need for investigations to establish average rates, modal characteristics, etc, so that comparisons could be made (Bardin, 1977).
Bardin mentions some lexical indicators:

- The TTR (type token ratio). This indicator allows measuring the richness or poverty of vocabulary, it is calculated between the different number of words over the total number of words (the higher the result, the greater the richness of the vocabulary present in the text).
- The analysis of co-occurrences, relates several elements of the text, finds simultaneous presence of two or more elements in the same message/text fragment.

- The association in which some units are associated and manifest in the user's language. We can distinguish association from co-occurrence because in association, unit A appears with unit B, unit A or unit D appears in identical contexts.

Briefly, the frequency of the units is based on the meaning in which the greater the frequency of the units, the greater their importance. However, in the co-occurrences of two or more units, they reveal association or dissociation in the user's message, because if a unit A has a very high frequency, we can test the hypotheses that A and B are associated (Bardin, 1977).

2.5. Kano model

As seen so far, customer satisfaction can be crucial for a company's competitive advantage. Therefore, having a continuous improvement strategy is important for a good performance in relation to customer perspectives.

Thus, Kano Model argues that customer satisfaction increases drastical a lot with only a few improvements in the performance of some attributes of the product or service, however, for other attributes, customer satisfaction increases very little, even when performance is improved (Sauerwein et al., 1996).

By using the model it is possible to classify quality attributes, however, the model says that the attributes of products or services should be classified according to whether they bring customer satisfaction or dissatisfaction with the level of performance (Huiskonen & Pirttlla, 1998). However, when there is an increase in the performance of a quality attribute it does not mean that there is an increase in customer satisfaction, some attributes are more important than others as it differs from customer to customer.

The quality of a service is evaluated by customers taking into account its attributes and dimensions. For example, in a hotel, the offer of a dessert can bring satisfaction, however, cleaning is already seen as an obligation and if it is not done well, there will be customer dissatisfaction, but if it is done well, it won't be a surprise or satisfaction for the consumer. Kano's model helps to understand how users evaluate their experiences and the quality attributes of the service or product (Lofgren & Wittel, 2005).

The Kano Model has 4 attributes:

- Mandatory attribute: Customers are dissatisfied if this attribute is absent or performs poorly, but it is an attribute that, if present, will not bring customer satisfaction either.
- One-dimensional attribute: Customers are satisfied according to the level of performance, the higher it is, the higher the level of customer satisfaction, however it has a symmetrical impact, if there is a reduction in performance, there will also be a decrease in customer satisfaction. client.
- Attractive attribute: Customers have higher than normal satisfaction, however, the absence does not bring dissatisfaction, because the customer was no longer waiting.
- Indifferent Attribute: Does not bring satisfaction or dissatisfaction to customers.
- Reverse attribute: Customers are dissatisfied with high performance and satisfied with low performance.

3. INVESTIGATION

This investigation uses content, produced by users on digital platforms to reveal relevant information about the performance of hotel services, regarding to the quality of service attributes. This information is open and available, it just needs to be extracted and analysed to verify the presence of standards and information that help professionals in the hotel industry to make decisions.

Many studies reveal that the analysis of online reviews is still challenging because it has a very long structure. However, it is this long and open structure (data available for free) that allows us to extract and analyse in more detail the experiences and perspectives of customers about the services/products.

This investigation has a limited sample of 15 hotel units, located in Braga and Porto, but it does not represent the entire hotel industry of the two locations and, in addition, the data were only taken from a platform ('Booking'). Being a limitation on generalizing the findings to other markets, consequently, the data may not be sufficient to represent all customers.

3.1. Analysis techniques and indicators

The analysis techniques used in this investigation, used in order to obtain patterns and understand which service attributes are most important to customers, were:

- Shapiro Wilk normality tests. The results of Shapiro Wilk's normality tests determined the use of non-parametric Kruskal-wallis tests for hypothesis tests;
- Frequency of words in which a high frequency of certain words increases their importance, however, all units have the same weight, that is, all elements have the same importance (quantitative analysis);
- Weighted frequency in which it was established that the appearance of a given unit is more important than others (weighting system);
- Direction in which it can be favorable, unfavorable or neutral, reflects a qualitative character;
- A qualitative analysis of words by order of frequency;
- Comparison of the characteristics of some speeches with others;
- The TTR (type token ratio). This indicator allows measuring the richness or poverty of vocabulary, it is calculated between the difference of the different number of words over the total number of words (the higher the result, the greater the richness of the vocabulary present in the text);
- The analysis of co-occurrences that relates several elements of the text, finds simultaneous presence of two or more elements in the same comment;
- The association/correlation in which some units are associated;
- Kano Model;
- Pareto diagrams and tree diagrams.

3.2. Data collection

Data were collected from the 'Booking' platform, where 1209 reviews were collected from 15 hotels of 3 to 5 stars, from the 1st half of 2021 to the 1st half of 2022. The variables collected are: Hotel name; hotel stars; Pool; Fitness center; SPA and Wellness Center; Restaurant; Pub; Location; Quarter; Genre; Nationality; Overall score; Nights; Type of room; Comment title; Positive Comments; Negative comments.
'Booking' is an online evaluation platform where it is possible to make a numerical evaluation from 1-10, being a quantitative indicator, as it is only a general evaluation of

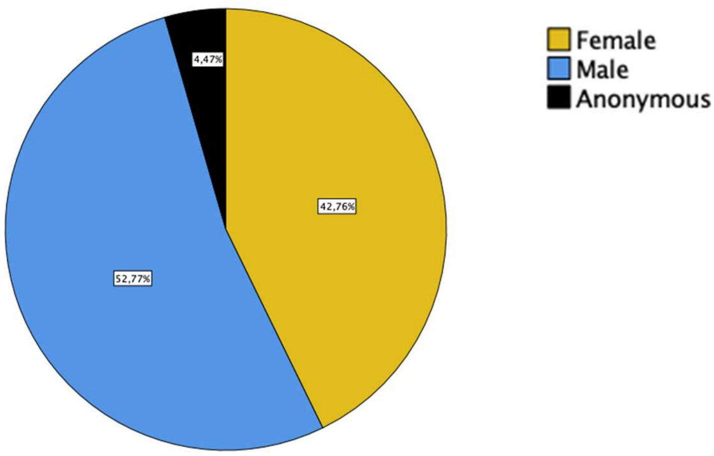
the experience. However, a quantitative evaluation does not give us the information of what liked or disliked, becoming a very general assessment and it is not possible to fully understand the customer. In 'Booking' it is also possible for the user to leave a positive and negative comment and thus justify the quantitative assessment through a qualitative evaluation and to understand the feelings and requirements of each user, because it is important to take into account that each user attaches different importance to different service attributes and, therefore, it is necessary to identify which service attributes contribute most to customer satisfaction. Through this information, the company can act more effectively and efficiently at these points and offer quality services, in accordance with the customer's requirements.

The gender of the user who made the comment was identified based on the username, allowing the classification as female and male or anonymous when it was not possible to clearly identify, because many users use nicknames and other non-specific names instead of their first name.

3.3. Sample characterization

3.3.1. Genre

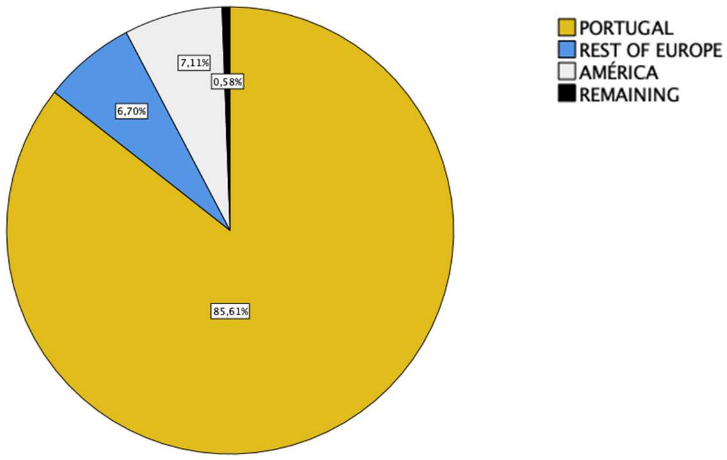
Of the 1209 comments, 52.77% were made by male users and 42.76% by female users and only 4.47% of the comments are anonymous or without identified gender. Thus realize that more men use 'Booking' to express their opinion about the service and there are users who do not like to identify themselves to comment on their experience on a digital platform.



Graphic 1 – Users gender.

3.3.2. Nationality of Users

The users nationality variable were divided into 4 categories Portugal, Rest of Europe, America and Remaining, to make the analysis easier, it is easily understand that 85.61% of the comments come from Portuguese users and only 14.39% of users are from another parts of the world.



Graphic 2 – Nationality of Users.

3.3.3. Services

The hotels were chosen taking into account the number of reviews, in the areas of Braga and Porto, five hotels with five stars, five hotels with four stars and five hotels with three. These presented more comments and, consequently, more information for analysis. When hotel stars are mentioned, it is not the users' rating, but the hotels stars.

4. RESULTS AND INTERPRETATION

4.1. Hypothesis Testing

Shapiro Wilk's normality tests were performed on the quantitative variables, demonstrating the absence of a normal distribution in all quantitative variables. The results of Shapiro Wilk's normality tests determined the use of non-parametric Kruskal-wallis tests for hypothesis tests.

After data collection, the data were transposed for statistical analysis and test hypotheses were formulated, crossing the variables, making it possible to arrive at some results that support the investigation and answer some of the questions raised.
It was observed that:

- the number of nights does not influence the general score given by the user, since the average number of nights is 1.72, practically 2 nights per user;
- the users nationality influences the overall score, customer requirements depends on their nationality, which may be associated with different cultures and habits;
- the hotels stars influence the general score given by the user, and it is possible to observe that hotels with more stars have better overall scores;
- whether or not the hotel has a pool influences the overall score given by the user, hotels with a pool have slightly better overall scores;
- the fact that the hotel has or does not have a Fitness Center and SPA influences the general score given by the user, however it is a minimal influence;
- the fact that the hotel has or does not have a restaurant influences the overall score given by the user, hotels with a restaurant have significantly better overall scores;
- the fact that the hotel has a bar or not does not influence the general score given by the user. This question is conditioned to the fact that all the hotels used in this investigation have a bar;
- the average number of nights is independent of the room type, here are better or worse rooms in the opinion of users;
- the location of the Hotel is not independent of the general score given by the user, because the location is important to the user;
- the average number of nights is not independent of the hotels stars, therefore, users choose hotels with more or less stars, also taking into account the number of nights they wish to enjoy;
- the quarter does not influence the general score given by the user, since users do not take into account the attribution of the general score by the time of year they use the service. However, the average number of nights is not independent of the quarter, or that is, users stay more nights at certain times of the year;
- Hotel stars influence the choice of room type, this is due to the fact that hotels with more stars have more options than those with fewer stars.

4.2. Users' comments

4.2.1 Positive Comments

The positive comments variable allows us to assess which aspects are most important and which stand out most positively in the quality of hotel service, in the opinion of users. It was possible to collect 13.913 words from the 1209 positive comments and 1706 different words, resulting in a TTR of 0.1226, that is a very low value, allowing the conclusion that the comments have a poor vocabulary. However, positive comments have an average of 12 words.

When looking at Table 1, the most frequent word is "small" and the second is "lunch", with this, it is possible to conclude that users give a lot of importance to breakfast in hotel services, then we have highlighted words such as "localization", "employees", "sympathy", "comfortable", "view", "pool", "bed" and "cleaning". These words define the most important attributes among the 1209 comments collected. A higher frequency of these words means, from the outset, that they are attributes of high importance, however, the frequency indicator gives the same weight of importance to each word and, when using a weighted frequency, it is assumed that the fact of the word "small" appears initially with 333 occurrences, it does not mean that it is a more important word than "lunch", because the high frequency of the word "small" may be related to "breakfeast" taking into account that the word "small " and "lunch" appear together 322 times (correlation) in the positive comments, this means that the lunch attribute is less important to customers than breakfast.

As in 'Booking' it is possible for users to write a positive and a negative comment, it is possible to say that the direction of the words that occur most is in a positive way or it can also be neutral.

Table1 – Most frequent words used in positive comments.

	Words	**Frequency**		**Words**	**Frequency**
1	small	333	11	bed	86
2	lunch	329	12	cleaning	75
3	localization	277	13	friendly	64
4	employees	209	14	quality	57
5	hotel	209	15	staff	57

6	excellent	155	16	attendance	55
7	sympathy	135	17	bedrooms	51
8	comfortable	92	18	decoration	45
9	view	91	19	comfort	42
10	pool	89	20	space	42

After analyzing the frequency of words, co-occurrences and correlations/associations are observed, relating several elements of the text it is possible to find several simultaneous presences in the same comment and correlations in which element A always appears with element B. The co-occurrences were collected and the correlations for the most frequent word, which is the word "small", was being noticeable that the word "lunch" occurs 359 times, close to the word "small", in the same sentences, it means that customers give prominence to "breakfast" and not to "lunch".

4.2.2. Negative comments

The negative comments variable makes it possible to analyze the characteristics of the services to be improved, but also attract more attention from users. It was possible to collect 23,896 words from the 1209 negative comments and 3327 different words, resulting in a TTR of 0.139, which allowed to conclude that negative comments also have a poor vocabulary. However, negative comments averaged 17.1 words per sentence.

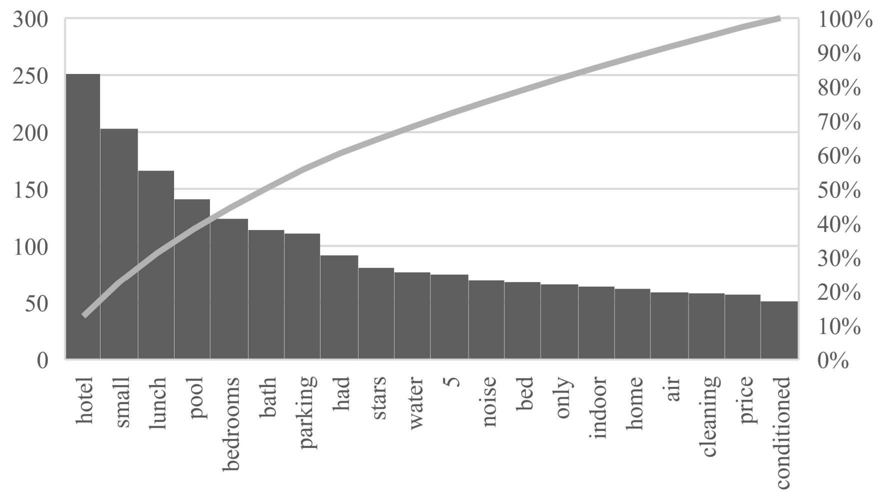
After analyzing Table 2, the most frequent word is "hotel", and it does not provide information about the service, then the second most frequent word is "small", which coincidentally is also the most frequent word in the positive comments, that is, as mentioned earlier, customers attach great importance to "breakfast" in hotel services, being one of the biggest attributes to take into account; followed by words, such as "pool", "bedrooms", "bath", "parking", "noise", "cleaning", "bed", "air", "conditioning". These words define the attributes that stand as the most in a negative way, from the customers' point of view. However, these words, as they are the most frequent, they are also the most important, having all the same weight. However, the weighted frequency allows us to assume that some words such as "hotel" are less important than "pool", because it is associated to a "4 stars hotel..." which does not provide relevant information in terms of quality, as words such as "lunch" and "small" are related to breakfast and the two words appear simultaneously 164 times, this means that lunch has little importance in the negative comments.

These words were evaluated in the negative direction as they were purposely made in a negative way.

Table 2- Most frequent words used in negative comments.

	Words	Frequency		Words	Frequency
1	hotel	251	**11**	5	75
2	small	203	**12**	noise	70
3	lunch	166	**13**	bed	68
4	pool	141	**14**	only	66
5	bedrooms	124	**15**	indoor	64
6	bath	114	**16**	home	62
7	parking	111	**17**	air	59
8	had	92	**18**	cleaning	58
9	stars	81	**19**	price	57
10	water	77	**20**	conditioning	51

Through the Pareto diagram, a quality tool, the information is clearly observed, as it orders the frequency of the 10 main problems mentioned by customers, in the hotel service, which will allow to prioritize which main problems need intervention in order to improve the service.



Graphic 3 – Main problems found.

As previously done in the positive comments, after analyzing the frequency of words, we also have the co-occurrences and correlations/associations. The co-occurrences and correlations for the word "pool" were collected and it was possible to understand that the biggest criticisms were made to the indoor pools, however, the criticisms also cover the water temperature and the size of the pool.

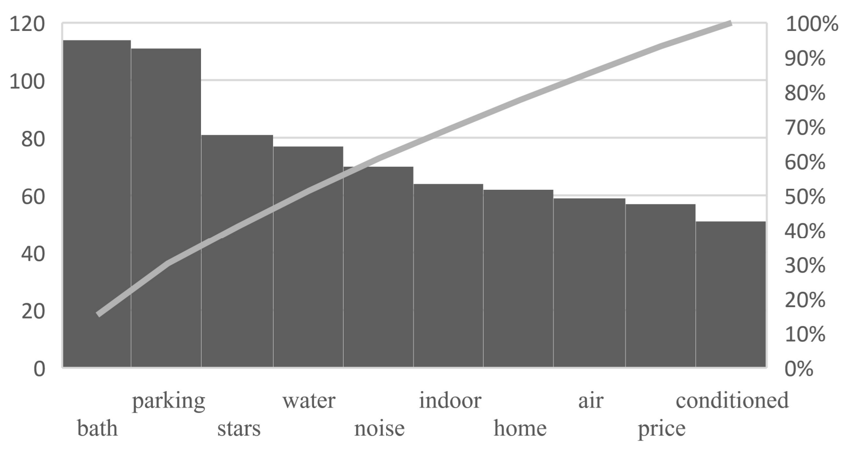
5. APPLICATION OF THE KANO MODEL

As seen before, customer satisfaction is related to the quality of service, and this can dictate the success of a company. Through the Kano Model, it was possible to analyze the attributes mentioned by the customers, in the comments, that drastically increase their satisfaction.

The Model has 4 attributes that relate customer satisfaction to performance of service:

- ***Mandatory attributes***

When analyzing the comments, the mandatory attributes are the attributes most present in the negative comments, but which are not present in the positive comments. Users were dissatisfied with the absence or low performance of this attribute, but when it is present, they do not show satisfaction. In Graph 4, the 10 most mandatory attributes mentioned by customers can be observed.

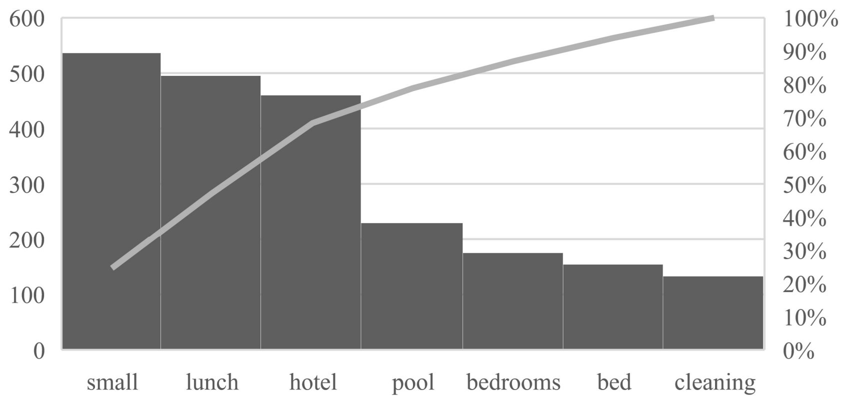


Graphic 4 – Mandatory attributes.

Therefore, for customers, the mandatory attributes that must be present in the hotel service are: bath (it is related to the bathroom and baths with hot water), parking, noise (no noise), price (take into account the quality-price) and air conditioning.

- ***One-dimensional attributes***

When analyzing the comments, the one-dimensional attributes are the attributes present in both positive and negative comments, so users are satisfied according to the level of performance. However, if there is a reduction in performance, there will also be a decrease in satisfaction, of the user. In the Graph 5, the 7 most commented one-dimensional attributes can be observed.

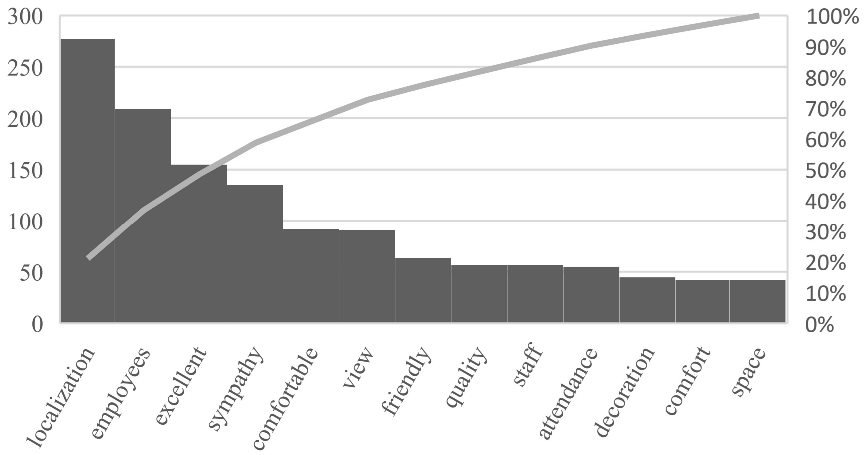


Graphic 5 – One-dimensional attributes.

The one-dimensional attributes, which should perform well in the hotel service, are: breakfast, hotel, pool, bedrooms, bed and cleaning in order to satisfy customers requirements.

- ***Attractive Attributes, Indifferent Attributes, Reverse Attributes***

Attractive attributes are attributes that are more present in positive comments, but not present in negative comments. Users have above normal satisfaction, however their absence does not bring dissatisfaction. In Graph 6, 13 of the attractive attributes can be observed.



Graphic 6 – Attractive Attributes.

Attractive attributes are important for the service to differentiate from the competition, because it does not bring dissatisfaction to customers if they are not present, but it satisfies the customer in a way that even leads them to demonstrate their satisfaction on digital platforms without any obligation. With this, customers attach great importance to attributes such as: localization, sympathy of the staff, comfort, view, quality, decoration and space.

- ***Indifferent attributes***

When analyzing the comments, these attributes are the ones that do not appear or they are almost never mentioned, they are indifferent attributes for customers, such as safety - eliminating dangers, is a less mentioned service attribute, it was only mentioned 13 times in 1209 comments (7 times positive and 6 times negative).

- ***Reverse Attributes***

Through the comments we were not able to understand which are the reverse attributes, because users are dissatisfied with the high degree of performance and satisfied with low performance.

6. TREE DIAGRAM APPLICATION

The tree diagram allows you to analyze the cause of the problems and to make possible to build it, you must expose a problem and then ask why this problem occurs. Therefore, the most important problems mentioned by customers in the comments are the mandatory and one-dimensional attributes presented in Kano's model, as users are dissatisfied with the absence or low performance of these attributes.

Therefore, the needs most expressed by customers are a good breakfast service and a good swimming pool.

A good breakfast service is related to a good service and the variety that is offered, with this, the tree diagram in Figure 1, allows you to understand all the tasks and paths in order to achieve the satisfaction of the customers in what breakfast concerns.

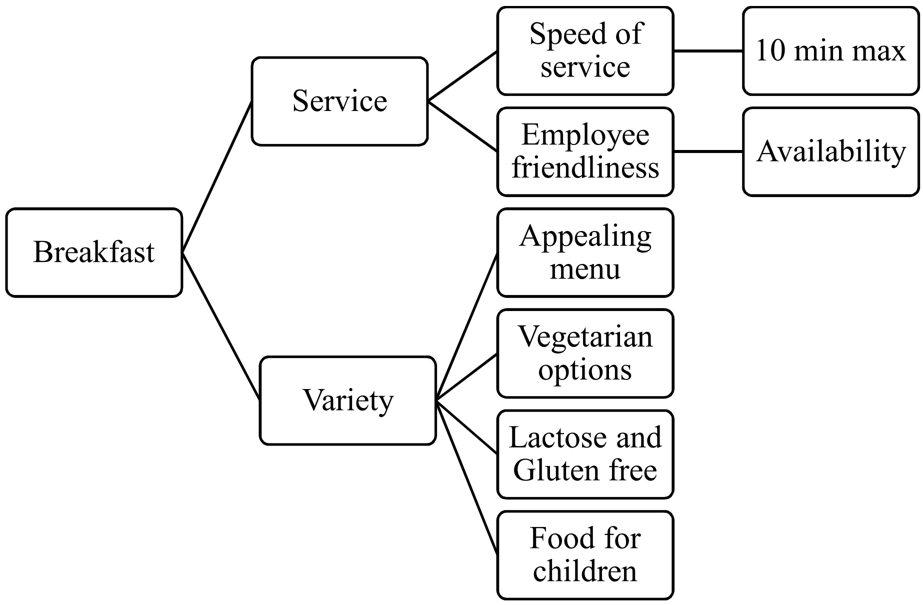


Figure 1 – Tree diagram for the breakfast problems.

Previously, it was possible to verify that the biggest criticisms were made to indoor pools, however, a good pool, both indoors and outdoors, is related to water and space. With this the tree diagram in Figure 2 allows to understand all tasks and paths in order to reach the objective of a swimming pool that pleases customers.

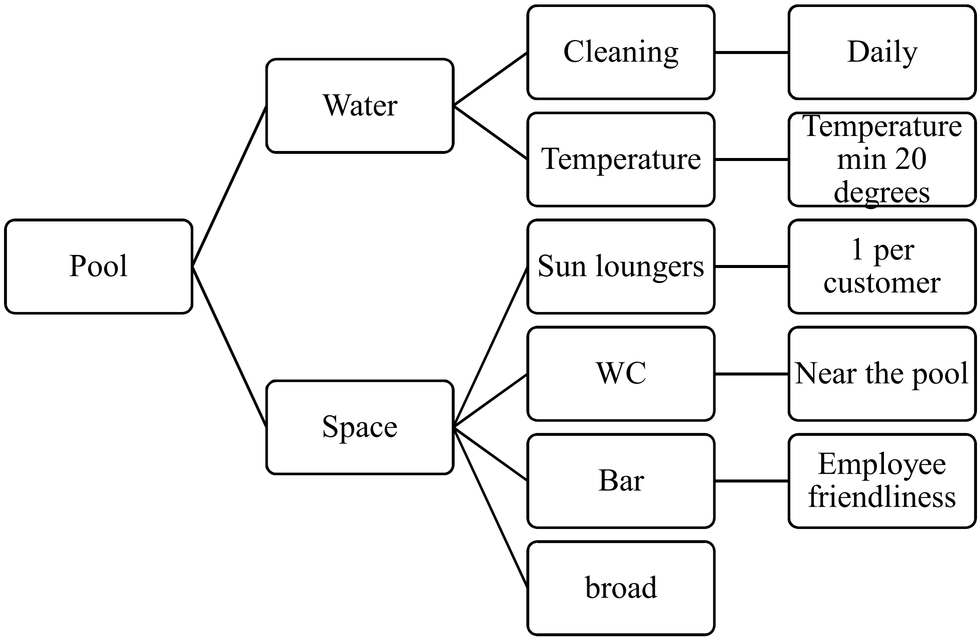


Figure 2 – Tree diagram for the pool problems.

In short, although these service quality attributes appear to be simple and implicit requirements by customers, there is a lot of work to be improved and reinforced by companies, in order to please and increase their customers.

The tree diagrams offer a global and simplified view of the improvements, which can be implemented, in order to reach a final objective, which is the improvement of the attributes most criticized by the customers. However, it was only possible to find them when the analysis of comments were provided directly by the customer. The solutions presented are suggestions for improvements, taking into account the existing problems. However, it is possible that there are more paths and tasks in order to solve these failures.

7. CONCLUSIONS

This investigation is a great challenge, as there are many gaps, however, the extraction of unstructured text from digital platforms, to be later analyzed, allowed to obtain important information about the general performance of hotel services, namely, what are the needs of improvement, market demands, among others. However, professionals and researchers should be aware that more technical knowledge is needed to carry on a more in-depth analysis in order to achieve the intended results.

The objectives were achieved because the information collected after being analyzed proved to be important, abundant and identified the profile of the customers.

To develop this investigation, four steps were considered in terms of quality in order to obtain significant results:

- Collect information directly from the customer about the quality of the service (online comments);
- Information categorization;
- Analysis of information to detect patterns of customer requirements;
- Presentation of service improvements.

This investigation allows companies to have a brief overview of the potential that digital platforms make it possible to obtain, free of charge, with regard the contact with the customer, making it very important for the quality of products and/or services and on the your opinions. As seen earlier, if companies identify 10 problems and solve 2, it can result in an 80% reduction in criticism.

This investigation had limitations in terms of the information collected, as it is limited to 1209 comments, a single digital platform and a year of information, which encompasses Covid-19.

The main measures that must be implemented by hotel companies to improve the quality of their services are summarized in a good performance in the service attributes that are mandatory and one-dimensional: a good breakfast service, a good swimming pool, parking space, quiet and air conditioning.

At the same time, it was possible to understand that to be a differentiator in the hotel industry, it is necessary to present a good performance in attractive service attributes such as location, friendliness of the staff, comfort, view, quality, service, decoration and space.

Finally, companies need to be open to change and attentive to the digital world, as the methodology applied throughout this research proved to be efficient and effective in order to improve the quality of services.

BIBLIOGRAPHIC REFERENCES

- Berelson, B. & Lazarsfeld, P. F. (1954). The analysis of communications content, Universíty of Chicago and Columbia University, Preliminary Draft, Chicago e Nova Iorque, 1948: depois, B. Berelson, Content analysis in communication research, Glencoe, IH, The Free Press, 1952; e B, Berelson, "Content Analysis em G. Lindzey" (org.), Handbook of Social Psychology, Cambridge, Addison- Wesley Publishing Co.

- George, A. L. (1959). "Quantitatíve and qualitative approaches to content analysís', in I. de Sola Pool, op. cit., , pp. 7-32.

- Lagrosen, S.O., & Grundén, K. (2014). Social media marketing in the wellness industry, The TQM Journal, Vol. 26 No. 3, pp. 253-260, available at: https://doi.org/10.1108/TQM-12-2013-0129 (accessed 14 April 2022).

- Ayeh, J., Au, N., & Law, R. (2013). “Do we believe in TripAdvisor?” Examining credibility perceptions and online travelers’ attitude toward using user-generated content. Journal of Travel Research, 52(4), 437-452.

- Barbier, G., & Liu, H. (2011). Data mining in social media. In C. C. Aggarwal (Ed.), Social network data analytics (pp. 327–352). United States: Springer.

- Bardin, Laurence. (1977). Content analysis. Lisbon: Editions 70.

- Bateson, J., & Hoffman, K. D. (2015). Service Marketing Principles - Concepts, Strategies and Cases (4a North American Edition). CengageLearning.

- Berry, L. L., & Parasuraman, A. (1995). Marketing Services: Competing on Quality. (3rd ed.). Maltese.

- Bickart, B., & Schindler, R. (2001). Internet forums as influential sources of consumer information. Journal of Interactive Marketing, 15(3), 31-40.

- Bilgihan, A., Barreda, A., Okumus, F., & Nusair, K. (2016). Consumer perception of knowledge-sharing in travel-related online social networks. Tourism Management, 52, 287-296.

- Carpinetti, L. R. (2010). Quality Management, Concepts and Techniques. Sao Paulo: Atlas S.A., available at: https://producao.ufc.br/wp-content/uploads/2017/01/tcc-2016.1-beatriz-linhares-rodrigues.pdf (accessed 18 May 2022).

- Chatterjee, P., (2001). Online reviews: do consumers use them? In: Gilly, M.C., Myers-Levy, J. (Eds.), Advances in Consumer Research, vol. 28. Association for Consumer Research, Valdosta, GA, pp. 129–133.

- Cheng, V.T.P., Loi, M.K., (2014). Handling negative online customer reviews: the effects of elaboration likelihood model and distributive justice. J. Travel Tour. Market. 31 (1), 1–15.

- Crosby. P. B. (1979). Quality is Free. New York: McGraw-Hill.

- Daugherty, T., Eastin, M., & Bright, L. (2008). Exploring consumer motivations for creating user-generated content. Journal of interactive advertising, 8(2), 16-25.

- Dean, J., & Bowen, D. (1994). Management Theory and Total Quality: Improving Research and Practice through Theory Development. The Academy of Management Review, 19, available at: https://www.jstor.org/stable/258933?seq=1#metadata_info_tab_contents (accessed 11 May 2022).

- Deming, W. E. (2000). Out of The Crisis. Cambridge, Massachussetts: MIT Press.

- Fader, P., & Winer, R. (2012). Introduction to the special issue on the emergence and impact of user-generated content. Marketing Science, 31(3), 369-371.

- Feigenbaum, A. V. (1961). Total Quality Control. New York: McGraw-Hill.

- Filieri, R., & McLeay, F. (2014). E-WOM and accommodation: An analysis of the factors that influence travelers' adoption of information from online reviews. Journal of Travel Research, 53(1), 44-57.

- Finch, B. J. (1999). Internet discussions as a source for consumer product customer involvement and quality information: an exploratory study. Journal of Operations Management, 17(5), 535-556.

- Frei, F. X. (2008), The Four Things a Service Business Must Get Right, Harvard Business Review, April.

- González, M. E. A., Gândara, J. M. G., & Brea, J. A. F. (2006). Explanation of behavioral intentions through perceived quality and satisfaction in spa tourism in Spain. Revista Turismo, 17(2), 206.

- Gundecha, P., & Liu, H. (2012). Mining social media: A brief introduction. Tutorials in Operations Research, 1(4).

- Hassan, S., Nadzim, S., & Shiratuddin, N. (2015). Strategic use of social media for small business based on the AIDA model. Procedia-Social and Behavioral Sciences, 172, 262-269.

- He, W., Zha, S., & Li, L. (2013). Social media competitive analysis and text mining: A case study in the pizza industry. International Journal of Information Management, 33(3), 464-472.

- Holsti, 0, R, (1969). Content analysis for the social sciences in humanities, Addison-Wesley.

- Huiskonen, J.; Pirttilã, T. (1998). Sharpening logistics customer service strategy planning by applying Kano's quality element classification. Production Economics, v.56-57, p.253-260.

- Juran, J. M. (1951). Juran's Quality Handbook. New York: McGraw-Hill.

- Juran, J. M. (2002). A quality from the project: the new steps for the planning of quality in products and services. Translation de Nivaldo Montigelli J. São Paulo: Pioneira Tompson Learning.

- Kimes, S. (2008). The role of technology in restaurant revenue management. Cornell Hospitality Quarterly, 49(3), 297-309.

- Kotler, P., & Keller, K. L. (2006). Marketing Administrationg (12th ed.). Pearson Education.

- Lofgren, M; Wettel, L. (2005). Kano's Theory of attractive quality and packaging. Quality Management Journal, v.12, n.3, pp 7-20.

- Lovelock, C., & Wirtz, J. (2006). Marketing of Services: People, Technology and Results. (5th ed.). Pearson Universities.

- Mariano, R. M. (2021). Application of quality tools to increase man/cash productivity in the separation of products in a logistics distribution center of a food company. (Completion of course work of the Federal Technological University of Paraná.).

- Mendes, M. F. (2007). The impact of QAS systems on Portuguese SMEs. (Master's Thesis, University of Minho, Uminho, Portugall), available at: http://hdl.handle.net/1822/7967 (accessed 27 April 2022)

- Moore, S., & Lafreniere, K. (2020). How online word-of-mouth impacts receivers. Consumer Psychology Review, 3(1), 34-59.

- Neto, E. S. (2009). Continuous Improvement in Inforlândia.. DEGEIT - Aveiro.

-Oribe, C. (2012). The history of MASP. available at: http://www.ufjf.br/engenhariadeproducao/files/2014/09/2012_3_Luiza.pdf (accessed 16 May 2022).

- Paladini, E. P. (2004). Quality management: theory and practice. 2a Ed. São Paulo: Atlas.

- Park, D., Lee, J., & Han, I. (2007). The effect of on-line consumer reviews on consumer purchasing intention: The moderating role of involvement. International journal of electronic commerce, 11(4), 125-148.

- Pereira, Z. L., & Requeijo, J. G. (2008). Quality: Planning and statistical process control. Lisbon: Preface - Edition of Books and Magazines, Lda.

- Phillips, P., Barnes, S., Zigan, K. & Schegg, R. (2017). Understanding the impact of online reviews on hotel performance: an empirical analysis. Journal of Travel Research, 56(2), 235-249. doi: 10.1177/0047287516636481

- Rezvani, M., & Safahani, N. (2016). He effect of site quality on electronic word of mouth marketing through mediating variable of customer satisfaction (case study: Tiwall culture and art social network online shop). International Business Management, 10(4), 592-598.

- Richard, J., & Guppy, S. (2014). Facebook: Investigating the influence on consumer purchase intention. Asian Journal of Business Research, 4(2), 1-10.

- Saias, L. (2007). Services Marketing – Quality and Customer Loyalty. Catholic University Publishing.

- Sant'anna, J. S. , & Haddad, M. S. (2014). Service quality assessment: application of the modified Servqual scale in a café & bistro.. 33 f. Monograph (Specialization) - Marketing Course, Fluminense Federal Institute of Education, Science and Technology, Campos dos Goytacazes, RJ.

- Santos, C. D. (2008). Proposal for the Implementation of an FMEA in the TEKA steam oven. DEGEIT - Aveiro.

- Sauerwein, E. et al. (1996). The Kano model: how to delight your customers. International Working Seminar on Production Economics, v.1 of the IX, Austria, p.313-327, Feb.

- Shao, G. (2009). Understanding the appeal of user-generated media: a uses and gratification perspective. Internet research, 19(1), 7-25.

- Shirky, C. (2010). They're Coming - The Power of Organizing without Organizations. Lisbon: Actual Editora.

- Spreng, R. A., & Mackoy, R. D. (1996). An empirical examination of a model of perceivedservice quality and satisfaction. Journal of Retailing, 72(2), 201 – 214, available at: https://www.sciencedirect.com/science/article/pii/S0022435996900147 (accessed 5 May 2022).

- Taylor, S. A., & Baker, T. L. (1994). An assessment of the relationship between service qualityand customer satisfaction in the formation of consumers' purchase intentions. Journal of Retailing, 70(2), 163 – 178, available at: https://www.sciencedirect.com/science/article/pii/0022435994900132 (accessed 12 May 2022).

- Werkema, C. (2006). Lean Six Sigma: Introduction to Lean Manufacturing Tools. 1. ed. Belo Horizonte: Werkema Editora, v.4.

- Xiang, Z., Du, Q., Ma, Y., & Fan, W. (2017). A comparative analysis of major online review platforms: Implications for social media analytics in hospitality and tourism. Tourism Management, 58, 51-65.

- Yang, J., & Mai, E. S. (2010). Experiential goods with network externalities effects: An empirical study of online rating system. Journal of Business Research, 63(9-10), 1050-1057.

- Zeithaml, V. A., & Bitner, M. J. (1996). Services Marketing (1st ed.). McGraw Hill.

Risk management prioritization in medical device SMEs based on AHP analysis

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STRUCTURED ABSTRACT

Purpose - Risk management is crucial for the longevity of companies and it is also required by many standards and regulations, such as ISO 9001 and ISO 13485. Particularly for the medical device industry the standards are stricter, due to the level of risk that products can represent. However, each standard is particular on its requirements and establishing the risk management process can be challenging, namely for small and medium-sized enterprises (SMEs). This research aims to identify and prioritize the key features for the risk management of medical device SMEs.

Design/methodology/approach - The Analytic Hierarchy Process (AHP) was applied as follows: from the literature review and the above-mentioned standards the authors defined the problem, objectives, alternatives and identified 5 evaluation criteria and 8 evaluation subcriteria, organized in the hierarchical structuring of four matrices, which were the basis for data collection and analysis. Five experts from Brazilian and Portuguese companies operating in the sector were interviewed and asked to evaluate each of the matrices, establishing the relative importance among the criteria, for the calculation of local priorities.

Findings - The results led to the involvement of employees as the most important criterion for risk management, followed by employees training and qualification. Organizational culture was listed as the least important criterion, with four of the five evaluators considering training and qualification as a way to work towards a cultural change and encourage risk-based thinking.

Originality/value - Recent researches highlight the need for methodological and scientific support on risk management for the companies. This paper provides discussion regarding whether the literature reflects the reality of organizations and how the process is considered by them.

Keywords: Quality Management System, Risk Management, Analytic Hierarchy Process, Small and Medium-Sized Enterprises.

Paper type: Research paper.

INTRODUCTION

Managing risks is an intrinsic activity to organizations that along with quality management, becomes fundamental for the good performance and longevity of organizations (ISO, 2015; Luburić, 2018). Small and medium-sized enterprises (SMEs) from the medical device industry are exposed not only to risks inherent to their processes, products, and services, but also to external factors that can positively or negatively impact their activities and survival (Cusmano et al., 2018; Williams et al., 2019). In this context, standards for Quality Management Systems (QMS) arise, such as ISO 13485:2016 which is specific to the medical device sector and has its structure established based on ISO 9001:2015 (ISO, 2016).

The implementation of ISO standards as well as the operationalization of risk management are considered major challenges for SMES (Vasile, 2017; Fonseca and Domingues, 2018; Cusmano et al., 2018) and as a consequence, standards can be interpreted and implemented inconsistently (Wu et al., 2019). Standards are often implemented in companies only due their regulatory nature, as an obligation that only in few cases has its benefits considered (Ritcher and Sereșeanu, 2015; Guerra-Bretaña et al., 2017). In this context, practitioners and researchers discuss that companies are influenced by their interpretation of standards and regulations, especially in the field of risk management, and once their practices meet the standards and are validated in audits, they do not engage in the improvement of the process and opt for the isolated use of widespread methods (Onofrio et al., 2015; Guerra-Bretaña et al., 2017).

According to Björnsdóttir et al. (2021), the ISO standards that require risk management practices do not have definition and uniform description about the process, which makes its implementation even more challenging for organizations. The authors highlight the need for methodological and scientific support, as well as assistance in understanding the risk management process and its relevance to the context of companies (Björnsdóttir et al., 2021; Crovini et al., 2020). Thus, it becomes relevant to explore the scenario of companies in the sector and their risk management practices, in order to identify whether the literature reflects the reality of organizations and how the process is considered by them.

This work has as main objectives: to identify the key features for the risk management of medical device companies, both from literature and the standards applicable to the sector; to analyze and prioritize the criteria from the companies' perspective, through the application of the Analytical Hierarchy Process (AHP) method. The research had as object of study 05 small-sized companies inserted in innovation ecosystems, which operate in the medical devices sector and have a structured Quality Management System.

THEORETICAL BACKGROUND

Medical device industry

The medical devices sector is an industry of great value in the global scenario, with the European Union accounting for the second largest market in the world (Manita et al., 2019). In Portugal, exports in health have grown more than 100% in the last 10 years, and one of the main factors of the country's competitiveness is the high quality and degree of specialization of both the scientific industry in these areas and the available human resources, with emphasis on global cost (AICEP Portugal Global, 2020). In Brazil, the productive chain of the medical devices sector has a participation of 0.6% of the Brazilian GDP (Gross Domestic Product), with more than 13,000 companies that generate around 140,000 jobs, being composed mostly of micro and small companies (ABIMED, 2020).

When it comes to SMEs inserted in innovation ecosystems, the creation, development and growth of innovative companies are fundamental aspects in the improvement of economic and social factors of the countries. In addition, innovation ecosystems provide the involvement of several actors, promoting the emergence of interconnection structures between academia, government and companies (Anprotec, 2019; RNI, 2021). However, the growth of small businesses is related to their practical skills of strategy and business management (Williams et al., 2019), but such activities are considered major challenges for SMEs and relevant factors to their survival (Cusmano et al., 2018; Riascos et al., 2020; Björnsdóttir et al., 2021). The highly dynamic and competitive environment of the medical devices sector requires companies to invest heavily in innovation of their products and processes to maintain competitiveness (Cusmano et al., 2018; Miclăuş et al., 2019; BBC Research, 2021). In this sense, the complexity of the sector covers many different aspects, including those associated with regulations.

QMS, regulations and standards

Each country establishes its regulatory requirements based on international standards and its own context. However, some critical elements are common among them, such as the "product" and its "use" (Gudeppu et al., 2020). According to Lobato (2018), ISO 14971 (risk management) and ISO 13485 (quality management system) are some of the main regulations applicable to companies in the medical devices sector. In Brazil the regulations established by ANVISA (Agência Nacional de Vigilância Sanitária) and INMETRO (Instituto Nacional de Metrologia, Qualidade e Tecnologia) are legal requirements, and the compliance with the good manufacturing practices defined in the RDC No. 16/2013 (ANVISA, 2013), associated with the application of risk management, are essential for the good performance and compliance of companies in the sector (SILVA, 2019). In the Portuguese scenario, the country has INFARMED (Autoridade Nacional do Medicamento e Produtos de Saúde) which is responsible for regulating and supervising the medical devices sector, based on the European

Union's General Good Practice Guide (EU GMP) for licensing medical device manufacturers (INFARMED, 2022). The sector is also regulated by Regulation (EU) 2017/745 of the European Parliament and of the Council of 5 April 2017 on medical devices (Official Journal of the European Union, 2020), and all medical devices need the CE marking (TAYLOR et al., 2020). Even if ISO 13485 is not compulsory in some countries, any actions go through requirements related or based on the standard.

ISO 13485 has its structure based on ISO 9001 and determines as a requirement for its implementation, the adoption of the vocabulary established in ISO 9000:2015 (ISO, 2016). This relationship is based on the strong influence and dissemination of ISO 9001 in the quality management of companies. However, due to the great focus of this standard on customer satisfaction and continuous improvement, at each ISO 13485 update its requirements become more specific and focused on product and user safety (Sheffer et al., 2019; Hrgarek and Bowers, 2009).

Unlike ISO 9001, the standard ISO 13485 maintains in its scope the preventive actions requirement (item 8.5.3), which is associated to the risk management (ISO, 2016), making no mention of the concept of risk-based thinking adopted by ISO 9001:2015. Despite the different approaches, according to Geremia (2017) both standards are very important guides for manufacturers of medical devices, once both address risks as a fundamental aspect for organizations. However, the risk approach is one of the most challenging requirements for SMEs when implementing ISO management standards (Vasile, 2017; Fonseca and Domingues, 2018).

Risk management

The priority of a medical device is safety followed by efficacy, performance and usability (Kadambi and Alagumalai, 2020). In this context, managing risks becomes a fundamental part in the decision-making related to the objectives of the organizations (Geremia, 2017) and managing risks of medical devices requires an approach more directed to the safety of the product and its user (Malins et al., 2015), which makes complete sense if we consider that the application of medical devices takes place in contexts of patient’s vulnerability (Israelski and Muto, 2004; Li, 2019). Li (2019) highlights that as medical device manufacturers, it is critical to adopt risk management and quality control practices, both from a regulatory perspective and from the perspective of quality assurance of the product and its processes.

The standard ISO 14971:2019 establishes the requirements for risk management of medical devices, focusing on people and their safety starting with the patient, extending to the operator and other users and devices in the environment (Sauter et al., 2015; ISO, 2019). However, the existence of regulatory requirements does not imply in the use of specific methods and each organization defines the practices and tools that better fit their contexts to be adopted (Onofrio et al., 2015; Wang and Moczygemba, 2015), which lead to different interpretations and procedures, even for companies with similar characteristics.

As a consequence of the requirements and needs of organizations, quality management, the process of medical device development and risk management have become an integrated activity (Miclăuş et al., 2019; Kirkire et al., 2018). Also, to establish the risk management process requires considering comprehensive aspects that permeate the entire organization, ranging from its services and products to its business strategies, which involves different sources of risk (Geetha et al., 2020; Waters and Sobral, 2019; Kirkire et al., 2018; Hale et al., 2020).

The involvement of top management in the process becomes a widely discussed aspect in the literature and considered crucial in providing clear guidelines for assessing risks and defining strategies for monitoring and control (Rane and Kirkire, 2016; Hrgarek and Bowers, 2009; Ritcher and Sereșeanu, 2015). Furthermore, some authors also emphasize the importance of a multidisciplinary team for a successful risk management process (Kuhl et al., 2020; Geetha et al., 2020). Thus, the development of this research is based on the need evidenced in the literature to conduct studies that can contribute to organizations in the establishment and implementation of their risk management practices, guiding their practices to an approach that encompasses all relevant aspects, both from the regulatory and practical aspects.

RESEARCH METHOD

Analytic Hierarchy Process (AHP)

In order to achieve the objectives, the authors applied the AHP technique, a systematic method of synthesizing priorities structured by means of a hierarchy, very effective to solve problems of multicriteria decision for the most diverse areas and sectors (Saaty, 1980; Salgado et al., 2015). The AHP was developed by Saaty in the 1970s and until today it is the most used multicriteria method worldwide, providing the analysis of problems through hierarchical groupings, which allow the comparison in pairs of criteria, for the attribution of weights and priorities and also for the quantification of qualitative variables (Saaty, 1980; Saaty, 2013)

The mathematical modelling of the problem based on the AHP method, consists of three main steps: identification of decision criteria; definition of weights and priorities; synthesis of results (Salgado et al., 2015). In addition, to conduct the method the evaluators must be selected, in a number that the researchers judge suitable, avoiding large samples. The value judgments (or comparison) are attributed by the evaluators within matrices of pairwise comparison, where the criteria are evaluated according to their relative importance. In other words, it is a numerical representation that expresses the priorities of a particular group of experts (Mendes et al., 2016).

To standardize the evaluation, Saaty established a scale of degrees of importance (see Table 1) and from these judgments, the weights and priorities of the criteria and alternatives are inserted in a matrix Aij, where the data are paired, followed by the eigenvectors' calculation, which refers to the local priorities (Salgado et al., 2015).

Table 1: Scale for criteria pairwise comparison (adapted from Saaty, 2013)

Importance level	**Description**
1	The two criteria are equally important
3	One criterion is hardly more important than the other
5	One criterion is rather more important than the other
7	One criterion is much more important than the other
9	One of the criteria is extremely more important
2, 4, 6, 8	Intermediate values between adjacent opinions

In this method, the relative importance is obtained using the eigenvector w of the comparison matrix A, where λmax is the maximum eigenvalue (Equation 1). Given n alternatives {A1, A2, An}, the evaluator performs the pairwise comparison, for all possible pairs of alternatives, and a matrix A is obtained, where the element aij shows the preferential weight of Ai obtained by comparison with Aj. The eigenvalue is the consistency measure of a comparison matrix, calculated according to Equation 2, where λ = n which, in turn, refers to the matrix order.

$$Aw = \lambda max. W \tag{1}$$

$$\mu = (\lambda - n)/(n - 1) \tag{2}$$

After obtaining the eigenvectors, Saaty (2013) proposes the calculation of the Consistency Index – CI (see Equation 3), for which it is also considered a kind of scale, with values for the Random Consistency Index - (RI) that depends on the matrix size, as shown in Table 2. For the experts' judgments to be considered consistent, the CI should be less than or equal to 0.10, while obtaining indices greater than 0.20 suggests that the expert revalue their judgments (Mendes et al., 2016; Saaty, 1980).

$$CR = CI/RI \tag{3}$$

Table 2: Random Consistency Index (Saaty, 2008)

n	1	2	3	4	5	6	7	8	9	10
RI	0,00	0,00	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

The AHP is widely applied in the area of quality management for decision making and prioritization related to regulatory requirements, total quality management aspects, selection of certifying bodies, among others (Alvarenga et al., 2018; Lewis et al., 2005; Salgado et al., 2015; Souza-Mendes et al., 2016). In this research, the method is used to identify the most relevant criteria for risk management in the medical devices sector, from the judgments of 05 experts from medical device SMEs, who are described in Table 3. The selection of companies with distinct characteristics was chosen in order to analyse the relationship between the type of each company's QMS certification and its evaluated priorities, since despite being structured in alignment to ISO 9001 and ISO 13485, each company approach risk management in a distinct manner.

Table 3 – Experts characterisation

Company	Founding Year	ISO standards	Expert	Country
Company A	2007	-	Quality Director	Brazil
Company B	2012	ISO 13485	QMS responsible	Brazil
Company C	2007	ISO 13485 e ISO 9001	Development Agent	Brazil
Company D	2011	ISO 13485 e ISO 9001	Technical Director	Portugal
Company E	2016	ISO 13485	Regulatory Affairs Manager	Portugal

Definition of criteria and hierarchical structure

The selection of criteria and respective groupings were made based on the literature and considering some of the main standards applicable to the sector, such as ISO 13485, ISO 14971 and ISO 9001. Through Table 4 it is possible to identify each criterion, sub-criterion, its detailing and references considered. After the criteria definition, the hierarchical structure of the problem was established (see Figure 1), presented to the experts along with instructions for filling out the matrices and guidelines for the judgments.

Table 4 - Definition and detailing of criteria and sub-criteria related to risk management

Criterion	Sub-criterion	Description	References
Employee involvement (EI)	Strategic level (SL)	Leadership involvement on risk management	Rane and Kirkire (2016), Mendes et al. (2016)
	Tactical level (TL)	Managers and coordinators involvement…	Kuhl et al. (2020), Ritcher and Sereșeanu (2015)
	Operational level (OL)	Operators (shop floor) involvement…	Geetha et al. (2020), Schmuland (2005)
Organizational culture (OC)	-	To have quality and risk management as part of the company's culture, encouraged by leadership	ISO (2015), Mendes et al. (2016)
Terms for risks approach (RA)	Risks as opportunities and threats (OT)	Positive and negative aspects of the risks considered in the management process	Aggarwal and Aggarwal (2016), ISO (2015)
	Risks as failures/hazardous situations (FH)	Negative aspects of risks, considered as product failures or dangerous situations for the user	ISO (2016, 2019), Caines et al. (2015)
Training and qualification (TQ)	-	Training on concepts related to risk management, both addressed by the applicable standards and associated to the companies' practices	Geetha et al. (2020), Rivas et al. (2014), Wang and Moczygemba (2015), Kirkire et al. (2018)
Risk sources (RS)	Product and user - technical (PU)	Technical issues related to possible risks in product design, development and use	ISO (2020), Malins et al. (2015), Li (2019)
	Process - tactical (PR)	Tactical issues related directly or indirectly to production/product	Michael et al. (2018), Pane et al. (2019), Guerra-Bretaña and Flórez-Rendón (2018)
	Business and market - strategic (BM)	Strategic issues that may impact products and processes in the long term	ISO (2015), Hale et al. (2020), Águas and Sobral (2019), Kirkire et al. (2018)

The experts of companies A, B, C and E were interviewed and received information about the problem, objectives, use of the method and filling out the matrices. Furthermore, the matrices were sent by means of an Excel spreadsheet with the structured problem (Figure 2) and four matrixes to be filled in: the family matrix (5x5), in which the criteria of level 1 of the matrix (EI, OC, RA, TQ, RS) were evaluated; the 2x2 matrix, concerning RA sub-criteria (OT and FH); and two 3x3 matrices, with the EI and RS sub-criteria SL, TL, OL and PU, PR, BM, respectively. Data collection was finalized in January 2022.

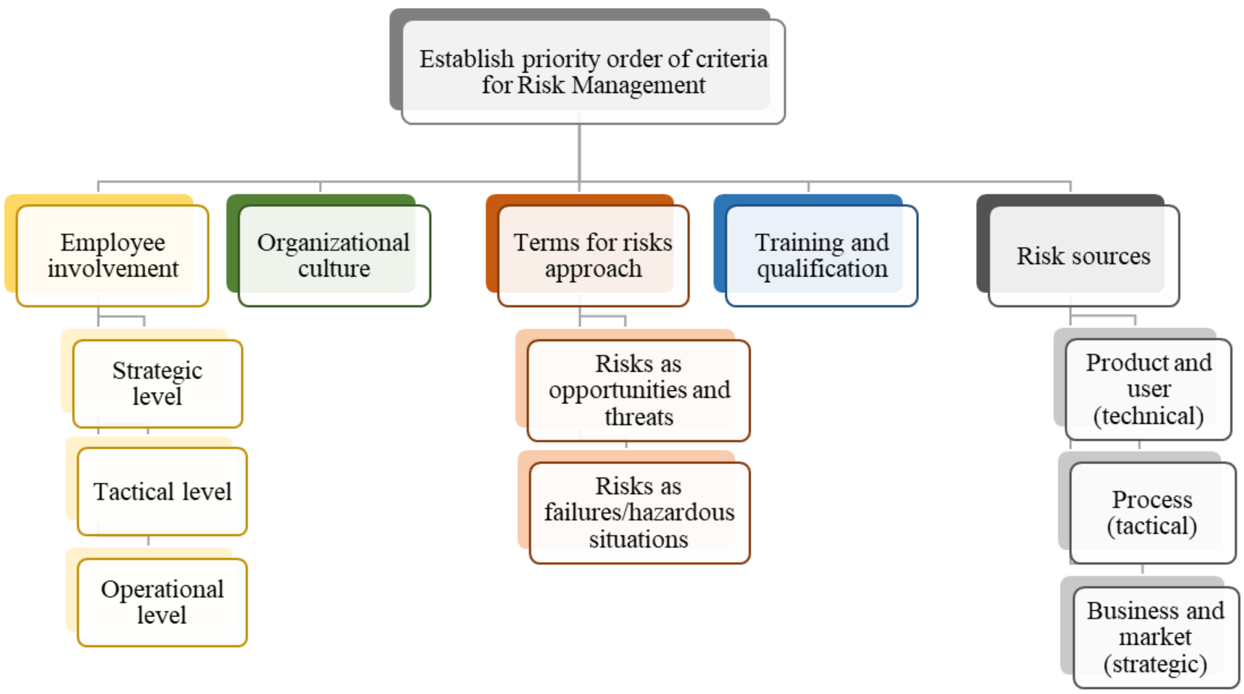

Figure 1 - Hierarchical structure of the problem

Data collection and analysis

From the pairwise comparisons carried out individually by each one of the five evaluators, the matrices were filled in and the tables composed by the individual evaluations, and respective local prioritization eigenvectors were calculated together with the consistency indexes, in the following order: Table 5 referring to the family matrix, of level 1 criteria; Table 6 referring to the matrix of subcriteria associated with the terms for risks approach; Table 7 referring to the matrix of subcriteria associated with employee involvement; and Table 8 referring to the matrix of subcriteria of risk sources. For the judgments with consistency indexes higher than 0.10, the researcher requested that the experts revalue their considerations, however, even after a new analysis they chose to keep the importance ratings, which they deemed to be coherent (Company D - family matrix - CI 0.18; Company C and Company E - 3x3b matrix - CI 0.12).

Following the detailed scale legend below, determine the relative importance of the criteria with respect to their priority for risk management. Which of these is least, most or equally important to the risk management process?

ATTENTION: You must assign importance only to the fields in blue

Family Matrix - Level 1 criteria

	EI	OC	RA	TQ	RS
EI	1				
OC		1			
RA			1		
TQ				1	
RS					1

Consistency Index	*Consistent judgments! Go ahead.*

CRITERIA LEGEND

EI	Employee involvement
OC	Organizational culture
RA	Terms for risks approach
TQ	Training and qualification
RS	Risk sources

Numeric scale

1/9	1/7	1/5	1/3	1	3	5	7	9
Extremely less	Much less	Rather less	Hardly less	Equall	Hardly more	Rather more	Much more	Extremely more

LESS IMPORTANT **MORE IMPORTANT**

Scale for pairwise comparison (Saaty, 2013)

Importance level	Description
1	The two criteria are equally important
3	One criterion is hardly more important than the other
5	One criterion is rather more important than the other
7	One criterion is much more important than the other
9	One of the criteria is extremely more important
2, 4, 6, 8	Intermediate values between adjacent opinions

Figure 2 - Model of the Excel spreadsheet sent to the evaluators for the Family Matrix

In the analysis of the Family Matrix (Table 5) the Company A, which does not have a certified QMS, considers as the most important criterion the involvement of employees, followed by training and qualification, and as least important, the definition of the terms for risks approach. The judgments of the specialist from this company are in line with the assessments of Companies B and E, both certified by ISO 13485, which consider the same criteria as the most important, disagreeing only on the least important, which for both experts is the organizational culture. The judgements of Companies C and D, certified by ISO 13485 and ISO 9001, diverge a little more than the others: for Company D, the organizational culture is the second most important criterion in risk management, the first being the involvement of employees and the least important being the sources of risk.

Table 5 - Comparison matrices with experts' judgements for the family matrix

Company A	**EI**	**OC**	**RA**	**TQ**	**RS**	**Local priority**	**CI**
EI	1	3	5	1	5	0.389	
OC	1/3	1	3	1	3	0.204	
RA	1/5	1/3	1	1/3	1/3	0.062	0.08
TQ	1	1	3	1	1	0.214	
RS	1/5	1/3	3	1	1	0.132	
Company B	**EI**	**OC**	**RA**	**TQ**	**RS**	**Local priority**	**CI**
EI	1	3	3	3	3	0.404	
OC	1/3	1	1/3	1/3	1/3	0.074	
RA	1/3	3	1	1	1	0.166	0.07
TQ	1/3	3	1	1	3	0.214	
RS	1/3	3	1	1/3	1	0.142	
Company C	**EI**	**OC**	**RA**	**TQ**	**RS**	**Local priority**	**CI**
EI	1	1	1	5	1	0.204	
OC	1	1	1/3	5	1/3	0.167	
RA	1	3	1	3	1	0.265	0.08
TQ	1/5	1/5	1/3	1	1/3	0.063	
RS	1	3	1	3	1	0.265	
Company D	**EI**	**OC**	**RA**	**TQ**	**RS**	**Local priority**	**CI**
EI	1	5	7	7	7	0.534	
OC	1/5	1	5	3	5	0.214	
RA	1/7	1/5	1	3	5	0.124	0.18
TQ	1/7	1/3	1/3	1	5	0.090	
RS	1/7	1/5	1/5	1/5	1	0.038	
Company E	**EI**	**OC**	**RA**	**TQ**	**RS**	**Local priority**	**CI**
EI	1	3	3	1	1	0.271	
OC	1/3	1	1/3	1/3	1/3	0.074	
RA	1/3	3	1	1/3	1	0.142	0.05
TQ	1	3	3	1	3	0.334	
RS	1	3	1	1/3	1	0.179	

Regarding the terms for risks approach analysed in the 2x2 Matrix (Table 6), experts from companies A, D and E consider "opportunities and threats" as the most important criterion; while companies B and C consider "opportunities and threats" and "failures and dangerous situations" as equally important criteria for risk management.

Table 6 - Comparison matrices with experts' judgements for the 2x2 matrix (RA)

Company A	OT	FH	Local priority
OT	1	3	0.750
FH	1/3	1	0.250
Company B	**OT**	**FH**	**Local priority**
OT	1	1	0.500
FH	1	1	0.500
Company C	**OT**	**FH**	**Local priority**
OT	1	1	0.500
FH	1	1	0.500
Company D	**OT**	**FH**	**Local priority**
OT	1	3	0.750
FH	1/3	1	0.250
Company E	**OT**	**FH**	**Local priority**
OT	1	5	0.833
FH	1/5	1	0.167

Although the involvement of employees was considered most important in risk management by all experts (in first and second places), the judgements of the subcriteria related to it presented divergences (Table 7). It was not possible to identify a relationship between the ISO certification of each company and the local prioritization established by the experts judgements: the involvement of strategic level employees is considered more important in risk management by Company B, certified only by ISO 13485, and by Company D, which has QMS certified by both ISO 13485 and ISO 9001; for the expert of Company C, which also has both certificates, the involvement of employees from the three organizational levels is equally important for the process; while for Company A, which has no certified QMS, and for Company E, certified in ISO 13485, the tactical and operational levels are equally more important in terms of involvement in the risk management process, considering the involvement of employees from the strategic level as less important.

Table 7 - Comparison matrices with experts' judgements for the 3x3a matrix (EI)

Company A	**SL**	**TL**	**OL**	**Local priority**	**CI**
SL	1	1/3	1/3	0.143	
TL	3	1	1	0.429	0.00
OL	3	1	1	0.429	
Company B	**SL**	**TL**	**OL**	**Local priority**	**CI**
SL	1	3	3	0.600	
TL	1/3	1	1	0.200	0.00
OL	1/3	1	1	0.200	
Company C	**SL**	**TL**	**OL**	**Local priority**	**CI**
SL	1	1	1	0.333	
TL	1	1	1	0.333	0.00
OL	1	1	1	0.333	
Company D	**SL**	**TL**	**OL**	**Local priority**	**CI**
SL	1	5	5	0.714	
TL	1/5	1	1	0.143	0.00
OL	1/5	1	1	0.143	
Company E	**SL**	**TL**	**OL**	**Local priority**	**CI**
SL	1	1/3	1/3	0.143	
TL	3	1	1	0.429	0.00
OL	3	1	1	0.429	

The same occurs in the analysis of risk sources considered in the process, compared in the 3x3b matrix (Table 8). Product and user risks are considered more important for risk management according to the judgements of experts from Companies B and E and, equally more important to the subcriterion business and market risks, for Company D. For Company C, business and market risks are the most important subcriterion for risk management, being process risks considered less important. On the other hand, for Company A, process risks are the most important subcriterion for risk management.

Table 8 - Comparison matrices with experts' judgements for the 3x3b matrix (RS)

Company A	PU	PR	BM	Local priority	CI
PU	1	1/3	1	0.200	
PR	3	1	3	0.600	0.00
BM	1	1/3	1	0.200	
Company B	**PU**	**PR**	**BM**	**Local priority**	**CI**
PU	1	1	5	0.480	
PR	1	1	3	0.405	0.03
BM	1/5	1/3	1	0.115	
Company C	**PU**	**PR**	**BM**	**Local priority**	**CI**
PU	1	3	1/3	0.286	
PR	1/3	1	1/3	0.140	0.12
BM	3	3	1	0.574	
Company D	**PU**	**PR**	**BM**	**Local priority**	**CI**
PU	1	5	1	0.455	
PR	1/5	1	1/5	0.091	0.00
BM	1	5	1	0.455	
Company E	**PU**	**PR**	**BM**	**Local priority**	**CI**
PU	1	3	3	0.574	
PR	1/3	1	3	0.286	0.12
BM	1/3	1/3	1	0.140	

RESULTS

The Table 9 describes the final prioritization of criteria, obtained from the arithmetic mean of the judgements of experts from companies A, B, C, D and E. Despite the existing divergences, data did not present a high standard deviation that would justify the use of the geometric mean. It can be seen that the most relevant criteria for risk management in the medical devices sector according to the participating experts is the involvement of employees (EI) at the strategic level (SL) with approximately 36%, followed by the tactical and operational levels considered by the experts as equally important. The second most important criterion for the process, according to the judgments, is training and qualification (TQ) and the criterion considered least important was organizational culture (OC), followed by terms for risks approach (RA) and risks source (RS), with about the same percentage.

Table 9 - Final criteria prioritization

Criteria	Global priority		Rank
Family Matrix - Level 1			
EI	0.368	36.8%	1º
OC	0.147	14.7%	5º
RA	0.152	15.2%	3º
TQ	0.183	18.3%	2º
RS	0.151	15%	4º
Matrix 2x2 - RA			
OT	0.667	66.7%	1º
FH	0.333	33.3%	2º
Matrix 3x3a – EI			
SL	0.387	38.7%	1º
TL	0.307	30.65%	2º
OL	0.307	30.65%	2º
Matrix 3x3b - RS			
PU	0.399	39.9%	1º
PR	0.305	30.4%	2º
BM	0.297	29.7%	3º

The experts' reports are in line with the studies identified in the literature, which characterize risk management as a practice that should be encouraged in organizations and that given its practical and normative rigor, is not something very intuitive for all employees, which leads to the need for knowledge dissemination about the process (Björnsdóttir et al., 2021; Crovini et al., 2020). Thus, it is possible to conclude that training and qualification in risk management, associated with the involvement of workers in the process, are means for the practices to be embedded in the organizational culture and therefore risk management becomes part of the culture of the company.

The terms for risks approach (RA) most important for carrying out risk management are risks as opportunities and threats (OT) with 66.7%, which is aligned with the requirements of ISO 9001 and the aspects discussed by Hale et al. (2020), Águas and Sobral (2019) and Miclăuş et al. (2019) that highlight the importance of considering all possible risks and benefits associated to the product. Finally, although the criterion risk sources (RS) were ranked 4th in the overall prioritization, the analysis of the subcriteria points to product and user (PU) risks and process risks (PR) as the most important for risk management, leading to business and market risks as less important. This can be explained by the fact that product and safety in terms of usability are critical factors in the medical devices sector. Generally, it was observed that being or not certified by ISO standards, especially regarding ISO 9001, has some relation with the experts' judgments, but it does not apply to all the analyses.

CONCLUSION

Through the AHP method it was possible to identify the most relevant criteria for the risk management process from the point of view of the experts from the medical device SMEs that was object of this study. Although the results cannot be generalized, the experts' judgments enable the identification of the scenario of the practices of these companies and therefore the establishment of recommendations that can be used as a basis for the development of new investigations. Thus, the research resulted in relevant analyses both for SMEs from the sector and for researchers, within the scope of risk management.

Considering the specificities of each company, namely regarding the certifications associated with QMS and risk management, it was expected that the behavior of the judgments would present some variation among the experts. However, the analysis of local priorities showed that there is similarity between some assessments. The research emphasizes that risk management is a comprehensive process and depending on the characteristics of each company and the interpretation of their experts, it can be understood and implemented in different ways.

Among the limitations of this research is the research method, both regarding the consistency index calculation and the number of evaluators. Although a large number is not indicated to avoid inconsistencies and complexity in the evaluations, it can bring a broader and more representative view of the problem. The development of this study enabled the analysis of the methods used by medical device SMEs for risk management, in progress for a new paper.

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REFERENCES

ABIMED - Associação Brasileira da Indústria de Alta Tecnologia de Produtos para Saúde (2020), “Acelerando a inovação no Brasil”, available at: https://abimed.org.br/ (accessed 13 November 2020).

Aggarwal, S. and Aggarwal, S. (2016) “Maintaining Regulatory Compliance in Medical Devices through ISO 13485 and 14971”, Cancer Therapy & Oncology Int J, Vol. 2, No. 3.

Águas, B. and Sobral, J. (2019), “Development of a Risk Management Tool for Healthcare Providers”, in IEEE 6th Portuguese Meeting on Bioengineering (ENBENG), 2019, pp. 1-4.

AICEP Portugal Global. (2020), "Comprar a Portugal – Fileira Saúde", available at: https://www.portugalglobal.pt/PT/sobre-nos/multimedia/fileiras/Documents/fileira-saude.pdf (accessed 16 February 2022).

Alvarenga, A.D., Salgado, E.G., and Mendes, G.H.S. (2018) "Ranking criteria for selection of certification bodies for ISO 9001 through the Analytic Hierarchy Process (AHP)", International Journal of Quality & Reliability, Vol. 35 No. 7, pp. 1321-1342.

Anprotec - Associação Nacional de Entidades Promotoras de Empreendimentos Inovadores. (2019), "Mapeamento dos mecanismos de geração de Empreendimentos Inovadores no Brasil", available at: https://informativo.anprotec.org.br/mapeamento-dos-mecanismos-de-geracao-de-empreendimentos-inovadores (accessed 15 November 2021)

ANVISA - Agência Nacional de Vigilância Sanitária. (2013), "Resolução da Diretoria Colegiada - RDC n° 16, de 28 de março de 2013", available at: https://bvsms.saude.gov.br/bvs/saudelegis/anvisa/2013/rdc0016_28_03_2013.pdf (accessed 11 November 2020).

BBC Research. (2021), "Medical Devices: Technologies and Global Markets", available at: https://www.bccresearch.com/market-research/healthcare/medical-devices-technologies-and-global-markets.html (accessed 16 February 2022).

Björnsdóttir, S. H., Jensson, P., de Boer, R.J. and Thorsteinsson, S.E. (2021), "The Importance of Risk Management: What is Missing in ISO Standards?", Risk Analysis.

Caines, P., Baird, P. and Whanger, K. (2015), "Eight common myths and misunderstandings about risk management", Perspectives on Risk Management, Horizons, pp. 13-17.

Crovini, C., Ossola, G. and Britzelmaier, B. (2021), "How to reconsider risk management in SMEs? An Advanced, Reasoned and Organised Literature Review", European Management Journal, Vol. 39, pp. 118-134.

Cusmano, L., Koreen, M. and Pissareva, L. (2018), "OECD Ministerial Conference on SMEs: Key Issues Paper", OECD SME and Entrepreneurship Papers, No. 7, OECD Publishing, Paris.

Fonseca, L.M. and Domingues, J.P. (2018), "Empirical research of the ISO 9001:2015 transition process in Portugal: motivations, benefits, and success factors", Quality Innovation Prosperity, Vol. 22, No. 2, pp. 16-46.

Geetha, V.G, Pharm, B. and Usha, S. (2020), "Risk Based Approach in Medical Device Quality Management System in Covid-19 Pandemic", International Journal of Economics and Management Studies, Vol. 7, No. 5, pp. 175-179.

Geremia, F. (2017), “Quality aspects for medical devices, quality system and certification process”, Microchemical Journal, Vol. 136, pp. 300-306.

Gudeppu, M., Sawant, S., Chockalingam, C.G. and Shanmugam, P.S.T. (2020), “Medical device regulations”, Trends in Development of Medical Devices, Academic Press, pp. 135-152

Guerra-Bretaña, R.M. and Flórez-Rendón, A.L. (2018), “Impact of regulations on innovation in the field of medical devices”, Research on Biomedical Engineering, Vol. 34, No. 4, pp. 356-367.

Guerra-Bretaña, R.M., Pérez-Álvarez, M.C., de Almeida, M.S. and de Sena, L.A. (2016), “Implementation of risk management activities within a quality management system. An osseous adhesive as case study”, in VII Latin American Congress on Biomedical Engineering CLAIB, IFMBE Proceedings, Bucaramanga, Santander, Colombia, pp. 5-8.

Hale, D., Fallon, E.F. and Fitzgerald, C. (2020), “An equipment qualification framework for healthcare”, IISE Transactions on Healthcare Systems Engineering, Vol. 10, No. 1, pp. 47-59.

Hrgarek, N. and Bowers, K.A. (2009), “Integrating Six Sigma into a Quality Management System in the Medical Device Industry”, Journal of Information and Organizational Sciences, Vol. 33, No. 1, pp. 1–12.

INFARMED - Autoridade Nacional do Medicamento e Produtos de Saúde, I. P, available at: https://www.infarmed.pt/web/infarmed/apresentacao (accessed 25 January 2022).

ISO - International Organization for Standardization. (2015). ISO 9001:2015 – Quality Management Systems – Requirements.

ISO - International Organization for Standardization. (2016). ISO 13485:2016 - Medical devices - Quality management systems - Requirements for regulatory purposes.

ISO - International Organization for Standardization. (2019). ISO 14971:2019 - Medical devices - Application of risk management to medical devices.

Israelski, E.W. and Muto, W.H. (2004), “Human Factors Risk Management as a Way to Improve Medical Device Safety: A Case Study of the Therac 25 Radiation Therapy System”, Joint Commission Journal on Quality and Safety, Vol. 30, Nº. 12, pp. 689-695.

Kadambi, P. and Alagumalai, V. (2020), “Designing for Safety and Efficacy: An Assessment of a Medtech Development Platform”, in International Conference on Communication Systems & Networks (COMSNETS), pp. 13-18.

Kirkire, M.S., Rane, S.B. and Singh, S.P. (2018), “Integrated SEM - FTOPSIS Framework for Modelling and Prioritization of Risk Sources in Medical Device Development Process”, Benchmarking: An International Journal, Vol. 25, No. 1, pp. 178-200.

Kuhl, J., Sankowski, O. and Krause, D. (2020), “Investigation on methods and characteristics in medical device development”, in Proceedings of the International Design Conference, pp. 1969-1978.

Lewis, W.G., Pun, K.F., and Lalla, T.R.M. (2005), “An AHP-based study of TQM benefits in ISO 9001 certified SMEs in Trinidad and Tobago”, The TQM Magazine, Vol. 17, No 6, pp. 558–572.

Li, F. (2019), “Research on Risk Management and Quality Control of Medical Devices Based on Humanized Concept”, in 5th International Conference on Economics, Business, Finance, and Management (ICEBFM 2019), pp. 731-735.

Lobato, K.C.D. (2018), “Sistematização de boas práticas para o processo de desenvolvimento e certificação de equipamentos médicos”, working paper, University of Itajuba, Minas Gerais, Brazil.

Luburić, R. (2018), “Creating a new model of managing change based on quality management principles and risk management principles”, Quality and Excellence (Kvalitet & izvrsnost, Beograd), Vol. 1-2, pp. 35-40.

Malins, R J., Stein, J., Thukral, A. and Waterplas, C. (2015), “SysML Activity Models for Applying ISO 14971 Medical Device Risk and Safety Management Across the System Lifecycle”, in 25th Annual INCOSE International Symposium (IS2015 proceedings).

Manita, A.D., Vikram, A.C.R. and Prabodh, C.S. (2019), “Regulation and Clinical Investigation of Medical Device in the European Union”, Applied Clinical Research, Clinical Trials & Regulatory Affairs, Vol. 7, pp. 1-19.

Mendes, G.H.S., Salgado, E.G. and Ferrari, B.E.M. (2016), “Prioritization of TQM practices in Brazilian medical device SMEs using Analytical Hierarchy Process (AHP)”, DYNA, Vol. 83, No. 197, pp. 195-203.

Michael, S., Mapunde, T.M., Elgar, N. and Brown, J. (2018), “A quality improvement study for medical devices usage in an acute healthcare setting”, Journal of Medical Engineering & Technology, Vol. 42, No. 5, pp. 344-351.

Miclăuş, T., Valla, V., Koukoura, A., Nielsen, A.A., Dahlerup, B., Tsianos, G. and Vassiliadis, E. (2019), “Impact of Design on Medical Device Safety”, Therapeutic Innovation & Regulatory Science.

Onofrio, R., Piccagli, F. and Segato, F. (2015), "Failure Mode, Effects and Criticality Analysis (FMECA) for medical devices: Does standardization foster improvements in the practice?", in 6th International Conference on Applied Human Factors and Ergonomics (AHFE 2015) and the Affiliated Conferences, AHFE, pp. 43-50.

Pane, J., Francisca, R.D.C., Verhamme, K.M.C., Orozco, M., Viroux, H., Rebollo, I. and Sturkenboom, M.C.J.M. (2019), "EU postmarket surveillance plans for medical devices", Pharmacoepidemiol Drug Saf, pp. 1–11.

Rane, S.B. and Kirkire, M.S. (2016). "Analysis of barriers to medical device development in India: an interpretive structural modelling approach", International Journal of System Assurance Engineering and Management, Vol. 7, No 11, pp. 356-3693.

Riascos, R.C., Ostrosi, E., Majić, T., Stjepandić, J. and Sagot, J.C. (2020). "A method to explore product risk in product lifecycle management of configured products", in Proceedings of the Design Society: DESIGN Conference, Vol. 1, pp. 687-696.

Ritcher, S. and Sereșeanu, A. (2015), "Developing Effective Risk Assessment Criteria in Regulated Environments", in 8th IEEE International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, 2015.

Rivas, T.R.P., Martínez, E.M., Sigler, A.F., Rubio, J.A.R., Fuentes, L.C., Méndez, J.F., García, T G. and Portieles, J.L.E. (2014), "Risk Management of Medical Devices in the ICID", in VI Latin American Congress on Biomedical Engineering CLAIB, Paraná, Argentina, pp. 718–721.

RNI - Rede Nacional de Incubadoras e Aceleradoras. (2021), "Monitorização das incubadoras portuguesas – Resultados de 2020", available at: https://www.rni.pt/conteudos/item/33-monitorizacao-das-incubadoras-portuguesas-2020 (accessed 18 October 2021).

Saaty, T.L. (1980), The Analytic Hierarchy Process, McGraw Hill, New York, NY.

Saaty T.L. (2008), "Decision making with the analytic hierarchy process", International Journal of Services Sciences, Vol. 1, No 1), pp. 83-98

Saaty, T.L. (2013), "The Modern Science of Multicriteria Decision Making and Its Practical Applications: The AHP/ANP Approach", Operations Research, Vol. 61 No. 5, pp. 1101–1118.

Salgado, E.G., da Silva, E.R.S., da Silva, C.E.S. and Mello, C.H.P. (2015), "An Analytic Hierarchy Process analysis for small and medium sized enterprises: prioritizing the practices of total quality management in Brazil", International Journal for Quality Research Vol. 9, No. 2, pp. 185-196.

Sauter, C., Heinloth, C., Ttobola, A., Pensky, N and Weigand, C. (2015), "Risk management for medical devices in research projects", Current Directions in Biomedical Engineering, Vol. 1, pp. 543–546.

Schmuland, C. (2005), "Value-Added Medical-Device Risk Management", IEEE Transactions on Device and Materials Reliability, Vol. 5, No. 3.

Sheffer, J., Bills, E.L., Clerkin, S., Walker, M. and Winter, M.H. (2019), "Improving Quality Management Systems: Short-term pain for long-term gain", Biomedical Instrumentation & Technology, pp. 48-54.

Silva, I.R. (2019), "Estudo das Regulações aplicadas ao Gerenciamento de Risco em Produtos para a Saúde - Estudo de caso: Equipamentos de fototerapia para neonatologia", working paper, Universidade Federal do Rio Grande do Sul, Porto Alegre.

de Sousa-Mendes, G.H., Salgado, E.G. and Moro-Ferrari, B.E. (2016), "Prioritization of TQM practices in Brazilian medical device SMEs using Analytical Hierarchy Process (AHP)", DYNA Vol. 83, No. 197, pp. 195-203.

Taylor, R.H., Kazanzides, P., Fischer, G.S. and Simaan, N. (2020), "Medical robotics and computer-integrated interventional medicine. Biomedical Engineering", pp. 617-672.

Vasile, F.A. (2017), "A critical approach of thinking risk-based existing in the new issue of ISO 9001: 2015 standard", EEA, Vol. 65, pp. 19-23, 2017.

Wang, T. and Moczygemba, J. (2015), "Risk Management in EHR Implementation", Journal of AHIMA (American Health Information Management Association), 2015.

Williams, R.I., Smith, A, Aaron, J.R., Manley, S.C. and Mcdowell, W.C. (2019), "Small business strategic management practices and performance: A configurational approach". Economic Research, Vol. 33, No 1, pp. 2378-2396.

Wu, F., Bills, E.L. and Eisner, J. (2019), "Advancing regulatory science through comprehensive, rational risk management", Biomedical Instrumentation & Technology, pp. 70-74.

Wu, Y., Li, F., Fan, Y. and Tu, P. (2016), "A Study of Medical Device Regulation Management Model in Asia. Expert Review of Medical Devices", Vol. 13, No. 6, pp. 533-543.

"Smart Police Station: A journey towards excellence, Dubai Police case study"

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Abstract

Purpose – The purpose of this study is to show the case of the innovative Smart Police Station (SPS) of Dubai Police through a case study that analyzes and discusses the Dubai Police continuous improvement, innovation and digital transformation challenges with SPS.

Design/methodology/approach –The data were collected from various sources including analysis of project reports developed by Dubai Police's Criminal Investigation Department and Smart Police Station team reporting on their activities during the project.

Findings –The results show that without develop and deploying digital technology, the task of fighting crime and protecting citizens becomes almost impossibly tough in a world where citizens and criminals alike are increasingly digitally sharps. Police forces and law enforcement agencies must learn to harness digital technology if they are to deliver a service that is fit for purpose in the 21st century.

Research limitations/implications – Further details and valuable implications are discussed throughout the study. The results have many practical implications, in that it can help Police Directors to make proper decisions when deciding to implement continuous improvement, innovation and digital transformation in their organizations.

Originality/value – This study is a rare and unique empirical study that examines the effect of innovation and strategic planning on the organizational performance of Dubai Police.

Keywords –*Public Sector, Continuous Improvement, Dubai Police, Innovation, Digital Transformation*

Paper type Case Study

1. Introduction

Demand on the police force continues to grow with continuously evolving crime threats crossing force, regional and national borders. Crime is however just a small proportion of the overall demand met by local police forces on a daily basis. Police forces and law enforcement agencies offers a service in general have a main duty in crime prevention and are in the proactive mindset to prevent crime. A brief review of the historical development of the efforts to prevent crime underscores the point that different technology has been the driving force leading to made changes of crime prevention, both by individual citizens and concerned groups, and by formal police agencies (Harris, 2007).

According to Garicano and Heaton (2010) although there is no significant relationship between general digital technology and crime fighting and deterrence, the productivity of the police increases when the adaptation to using digital transformation rises. Like other organizations, police forces acquire advantages in using digital transformation when they merge these technologies and their organizational practices to yield better performance.

Digital transformation affects all sectors of society, in particular their economies. Companies now are given an opportunity to radically change their business models by new digital technologies like social networks, mobile, big data, Internet of things, other innovations like blockchain. This mostly involves changes of the core business operations and modifies products and processes, as well as organizational structures, as companies ought to set up management practices to conduct these complex transformations (Matt *et al.*, 2015).

Traditionally, law enforcement agencies have had an unfriendly relationship with technology. However, there is no way one can ignore and/or resist the adoption of digital transformation any longer since recent developments in information technology have changed the attitudes and perceptions of police forces as well as criminals. The technological advances over the years have provided law enforcement agencies new perspectives and considerations beyond the traditional methods and opportunities to utilize a wide range of innovations in different contexts. The recent innovations and implementations which increase the efficiency and effectiveness of policing including network analysis, GIS, crime mapping, biometrics, CCTV, fingerprints, DNA research, facial recognition, speech recognition, social media policing, among others. (Tombul & Cakar, 2015)

The objective of this paper is to analyze a case study from Smart Police Station (SPS) of Dubai Police using continuous improvement, innovation and digital transformation to build a strong relationship with the citizens, residents and tourist of Dubai. SPS it is a tangible example of digital transformation strategy for a Police Force. This idea of a smart police station without human interaction was developed and implemented by Dubai Police, and it's the first and the only one in the world.

Since 1956, Dubai Police has been working to set a leading position and bring about positive reinforcing change for the citizens, residents and tourist of Dubai. The idea of the having a non-human interaction police station and ultimately the SPS evolves from years of enhancing Police services whilst keeping in trend with the latest and state of the art technology. SPS was launched in 2017, City Walk was the first SPS in Dubai, now they are 13 SPS in different strategic locations.

This article may be interesting for other police forces and law enforcement agencies worldwide in order to establish and begin the journey of continuous improvement, innovation and digital transformation. Using digital technology in traditional police station help Dubai Police to understand the importance of applying digital transformation to design and develop the idea of SPS.

2. Literature review about Police, Continuous Improvement, Innovation and Digital Transformation

Policing is widely described as involving the use of force in pursuit of goals of law enforcement, crime prevention and order maintenance (Lersch & Mieczkowski, 2005). The modern police organizations originated in the United Kingdom more than 150 years ago. Still struggling with the upheaval, the industrial revolution, U.K. at that time was grappling with a rise in crime, incivilities and police corruption. At that time, policing was based on a system of private guards while the army was called in to intervene in the most serious situations. The resulting insecurity became a dominant political and social concern throughout Europe. With the intensification of social disorders, justice and police administrators thought that some preventive police - non-military and non-partisan - could protect the public and rally its support (Emsley *et al*., 1994).

Worldwide Police Forces and Law enforcement agencies are now using a variety of newly developed technologies to fight against those criminals who are employing the advantages of these technologies for negative purposes. Nevertheless, law enforcement agencies may need to seek out more highly developed software and technologies to overcome these applications of technology by criminals which may be very sophisticated (Adderley & Musgrove, 2001).

2.1 Continuous Improvement

Different methodologies from quality and continuous improvement has been developed. Kaizen (*Kai – do, change, Zen – well*) is a kind of thinking and management, it is a philosophy being used not only in engineering companies or management field but also in the everyday life in Asia (mainly in Japan). It means gradual and continuous progress, increase of value, intensification, and improvement (Karkoszka & Rozak, 2005). It is translated in the west as ongoing, Continuous Improvement or CI (Malik *et al.*, 2007). The concept CI is associated with a variety of organizational developments including the adoption of lean manufacturing techniques, total quality management (TQM) employee involvement programmes, customer service initiatives and waste reduction campaign.

A continuous improvement process, as the name implies, has no end to it. In contrast, improvement routines are expected to be integrated into the organization's daily activities and used to generate results in line with the firm's strategic objectives. The most prominent examples, such as the Toyota Production System, are stable and facilitate the spread of practices through the company (Garcia-Sabater & Marin-Garcia, 2009).

Managers of any organization play a crucial role in the success of continuous improvement tools and techniques. Without the leadership, commitment and involvement of senior management, a continual improvement programmed is unlikely to be successful. We had been seeing organizations without clear understanding of continuous improvement plan and in few years, they have a lack of commitment to make this sustainable in the long run.

Continuous improvement is even more effective if it is introduced into an organization that has a learning culture. It is important to know and understand the culture of an organization. This will help identify what needs to be changed to promote continual improvement (Hitpass & Roman, 2020).

2.2 Innovation in a police force context

Moore *et al*. (1997) suggest four distinct categories of police innovation: programmatic, administrative, technological, and strategic. These categories are not clearly separated from each other and, as Moore *et al*. (1997) admit, assigning any one innovation to one category over another is often a judgment call. Programmatic innovations establish new operational methods of using the resources of an organization to achieve particular results.

Different authors in research for police forces performance refers the importance of using and adapting innovation and digital transformation to officers can help to have better performances (Wright, 1978; Colvin & Goh, 2005; George, 2005; Custers, 2012).

Wright (1978) commented that the aim of technology as used in law enforcement is to facilitate and provide efficiency in policing. Technology has also shifted the perception of the police and changed the character of traditional policing. Using technology in law enforcement also represents a change in police management and organization. In other words, there is a positive relationship between police management and adaptation to the new technologies.

Colvin and Goh (2005) emphasized the fact that the use of information technologies (IT) is an important factor affecting the performance of police work. In their study, it was proven that information quality and timeliness are two important components that are effective in terms of achieving the acceptance by patrol officers. George (2005) explained that law enforcement agencies should utilize all available information technologies when creating portals to merge decentralized databases since agencies may strongly demand a database that allows them to share crime data in cooperation with other institutions in the judicial area. The interesting thing is that criminals are professional enough to utilize IT for purposes of committing more crimes and defining more targets.

Custers (2012) enlightens us that law enforcement agencies do try to optimize the use of technology in criminal investigation and prosecution processes, but many of the users are not satisfied. Owing to their lack of insight about new technology, users might prefer to continue to use the current technology rather than the new technology.

Innovation in public/large organizations is receiving increasing academic interest. Case studies have focused on many fields, such as civic environmentalism (John, 1994), healthcare (Pillay & Morris, 2016), educational choice (Roberts & King, 1996) and policing (Bond & Gabriele, 2018).

Regarding innovation in police forces and law enforcement agencies, several authors and practitioners have pointed out that improving performance through innovation is rarely straightforward (Skolnick & Bayley, 1988; Reichert, 2001). In these Police Forces, resistance to change is high and police officers often experience difficulty in implementing new programs and initiatives regarding the use of new technologies (Skolnick & Bayley, 1988). It has been demonstrated that innovation among the police can prevent crime and can improve their relationship with the citizens that they serve (Reichert, 2001).

2.3 Digital Transformation

We reviewed the multidisciplinary literature to understand what is known about firms' digital transformation. To better understand the existent knowledge, the intersection of different fields must be studied rather than relying on a single field (Tarafdar *et al.*, 2018). A cross-discipline exchange of knowledge helps to better grasp the strategic imperatives of digital transformation, as it involves multiple functional areas, including marketing, information systems, innovations, strategic and operations management.

Digital transformation and resultant business model innovation have fundamentally altered consumers' expectations and behaviors, pressured traditional firms, and disrupted numerous markets. Consumers have access to dozens of media channels, actively and effortlessly communicate with firms and other consumers, and pass through rapidly increasing number of touchpoints in their customer journey, many of which are digital (Lemon & Verhoef, 2016).

Digital transformation affects the whole company and its ways of doing business (Amit & Zott, 2001) and goes beyond digitalization—the changing of simple organizational processes and tasks. It rearranges the processes to change the business logic of a firm (Li *et al.*, 2018) or its value creation process (Gölzer & Fritzsche, 2017). For instance, digital transformation in the healthcare sector is manifested by broad and deep use of IT that fundamentally changes the provision of healthcare services (Agarwal *et al.*, 2010). The use of IT is transformative and leads to fundamental changes to existing business processes, routines and capabilities, and allow health care providers to enter new or exit current markets (Li *et al*., 2018). Moreover, digital transformation utilizes digital technologies to enable interactions across borders with suppliers, customers and competitors (Singh & Hess, 2017).

Digitizing public services is, at the moment, an essential necessity for numerous governments around the world, and also for many police forces and law enforcement agencies. An improved government through digitization will not only have a growing effect on businesses, but it will also be able to intensify citizen engagement, key part for crime prevention.

The Digital transformation efforts is the paradigm shift from designing and delivering public services solely based on the internal – policy-driven logic of public administrations to an external, open and co-productive logic of co-designing public services. Previous efforts have left public administrations with problems of non-adoption or even rejection of public services, so that citizens opted to use analog services instead of online services. While these digitization efforts were intended to contribute to time and resource savings, they are oftentimes a replication of existing off line processes, without rethinking mission support or redesign of services, so that citizens are willing to accept them as a reliable alternative to meeting frontline workers in their physical offices. Alternatively, new forms of agility and responsiveness in service delivery are emerging that focus on approaches to co-design and coproduce together with the public (Mergel, 2016).

Impact of quality management systems on the performance of police forces in the context of digital transformation

Quality Management System achieved an increasing interest among practitioners and market players as an essential tool for creating a sustainable competitive advantage (Rashid et al., 2020). Moreover, the total quality management increase commitment to quality and enhance performance which will eventually lead to organizational competitive advantage (Kaur et al., 2019). The evaluating studies on important excellence factors and relationships and total quality management, along with various vital results factors that may be featured as crucial to possess the execution of total quality (Al-Maamari, 2020).

Technology and policing have been interconnected for decades, dating back to the advent of the telephone, the automobile, and the two-way radio. Today, technology seems to be advancing at an ever-accelerating pace, as seen through the propagation of mobile and wireless technology, high-powered computing, visual and audio technology, advanced analytics, and other technological advancements. Many departments are implementing these and other technologies to increase efficiency and to improve outcomes, especially in times of diminished resources and enhanced public attention to and scrutiny of law enforcement tactics and outcomes (Strom, K., 2017)

Technology has been considered a significant driver to law enforcement strategies and tactics for as long as can be remembered. In the 20th century, the introduction of the telephone, the automobile, and two-way radios created seismic shifts in what police do, pushing departments toward a strategy of rapid response to citizens' request for police assistance (Harris, 2007).

3. Research Methodology

There are different ways to develop a new hypothesis regarding a specific question and one of the most common approaches is called case study. Yin (2011) defines case study as an empirical enquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context are not clearly evident.

Case studies have been widely used in many areas of knowledge (Yin, 2011, 2013), and based in some different authors, general conclusions can be extrapolated to other cases of similar features to those observed in the study (Maxwell, 2008).

We will analyze the Smart Police Station (SPS). The Smart Police Station is an integrated interactive, innovate, self-service police station to provide smart services to citizens, residents, and visitors around the clock without human interaction. It is the first of its kind, which allows the community members to apply for Dubai Police services that are provided at traditional police stations (Román, 2016, 2019).

4. Results

The Dubai Police (DP) force was founded on the 1st of June 1956 in Naif, a historic neighborhood located in the Deira side of Dubai-UAE. The force grew from 29 members in 1956 to 25,000 in 2020. We cover an area of 4,114 square kilometers and a population of more than 4.7 million people in a city that has seen tremendous economic growth and a high level of urbanization. We come under the jurisdiction of the ruler of Dubai and we follow the motto of "Smart Secure Together" to reflect our core belief that technology, openness and tolerance are the corner stone of our identity. We provide service to a highly-diversified population that includes more than 200 nationalities.

Since 2017, when Dubai Police launched the Smart Police Station, became the first Police Force in the world to have unmanned police stations. According to finance department at Dubai Police, running a regular police station requires a financial sum of about US$2.2 million yearly as well as a large number of employees and trained force. SPS operations cost around US$330.000 per year.

How the SPS Works:

- Visitors enter the station's main doors and follow the floor signs to the big screen on the left side and choose between resident and tourist options.
- Residents must put their Emirates ID or passport for tourist, in a slot beside the screen and follow the steps on the screen.
- Visitors must enter their full personal details on a page on the screen and follow the steps on the screen.
- Choose a service and you will get a token to enter the cubicle service room.

As such, the development of the Smart Police Station was done to achieve the following: A complete, fully-functional, and smart police station that requires no human intervention. A lot of resources have been utilized to improve services at the SPS in Dubai. The Smart Police Station Express or SPS-Express is one of the latest innovations that is being rolled out. These emergency phone towers have night vision, video and audio talk, broadcast, alarm integration, remote monitor and HD CMOS camera. It is vandal-proof and connects via Wi-Fi and 4G LTE. The device is connected to a central SPS system and provides a range of police services.

To achieve the best organizational performance, police forces and law enforcement agencies needs to build capabilities in continuous improvement, innovation and digital transformation are considered important drivers in enhancing overall performance, and the effects of them examined in this study, with various results on continuous improvement, innovation and digital transformation.

4.1 Continuous Improvement

Building a culture of continuous improvement at Dubai Police starts with deploying the strategy (based on the Dubai Plan 2021) that involves measuring work, improving work, and changing work. The strategy is only effective when your employees have commitment to the organization and understand how to be innovative.

Back in 1990, Dubai Police began working in the journey of excellence, the foundation of the quality improvement was based on quality management principles and the culture of

Dubai Police to offer the best services to the residents and citizens of this dynamic city. Since 1997, 2.850 Dubai Police´s employees for all the departments have been trained in quality tools like: Business Excellence Frameworks (Dubai Excellence Government Program (4G), EQFM, Baldrige), Benchmarking (TRADE Methodology), Total Quality Management (TQM), Lean Management, Six-Sigma, ISO Standards, etc. All this tools & systems help Dubai Police to create an environment of strong and systematically culture of quality.

Dubai Police uses the Business Excellence Framework (EFQM, Baldrige and Dubai Government Excellence Program) and formal benchmarking (TRADE Methodology) to assess their performance in order to offer outstanding service to its stakeholders. In 2018 EFQM recognized Dubai Police with a prestigious International Award: "Prize Winner in Succeeding through the Talent of People & Sustaining Outstanding Results" (first Police Force in the World to achieve this prestigious award).

Dubai Police's services not only maintain security and stability, but try to exceed these and cover all of the requirements of Dubai's society. The DP's strategic plan contains objectives that meet or exceed the expectations and aspirations of its customers and guarantees their satisfaction, all of which stems from the strategic plan of the government of the Emirate of Dubai. DP has always strived to maintain the highest levels of comfort, security, and safe living for the emirate's visitors and residents. The fact that 98 percent of the people feel it is safe and secure to walk out at night in the UAE has helped rank the country as the world's second safest place. UAE's policies and strategies were behind that achievement (Gallup, 2019).

4.2 Innovation

United Arab Emirates has constantly been distinguished as an icon for innovation and creativity, enhancing its social and economic status and transforming into a primary destination for talents and businesses in record time. Believing that innovation is the future of human investment, the UAE Leadership emphasizes its importance across all sectors through the UAE Vision 2021: "Innovation, research, science and technology will form the pillars of a knowledge-based, highly productive and competitive economy, driven by entrepreneurs in a business-friendly environment where public and private sectors form effective partnerships." (UAE, Vision 2021).

The Smart Police Station is the first of its kind in the world, helping citizens and tourist of Dubai to use any service without the need of any human intervention. Through the user-friendly design, a customer obtains a digital ticket from the queue system then proceeds to navigate to the different service points, offering more than 60 different services.

Smart Police Station offers many different services to exceed the expectations of the customers, so every station has an interactive game that entertain visitors as well as allows them to learn about various safety rules in UAE. Aside from the interactive game, customers may get a virtual tour using the VR equipment or enjoy a variety of books and music regarding the history of Dubai and UAE. Some of the maim services offers are: Criminal Services, Traffic Services, Certificates/Permit Services and Community Services. All of services that SPS offered to the public are systematically assess by the Excellence & Pioneering Department of Dubai Police in order to see the performance and to improve the quality of the services. The assessment is based on the Business Excellence Framework that Dubai Government Excellence Program (similar to EFQM, Baldrige, etc.) use and promote to all the public sector in Dubai. Using continuous improvement tools in Police Forces and Law Enforcement agencies can help to build a strong foundation of quality programs and to in the case of Dubai Police these quality programs helps to offers a better service to the citizens and residents of Dubai-UAE.

Smart technology, AI and digital transformation help significantly improve the safety and security of a Dubai's citizens. Community policing and direct contact with citizens are essential components in creating a safer society. However, our public safety personnel do not always have access to the right resources and information to do their jobs effectively. The benefit of Smart Police Station is that it builds on this strong foundation. SPS stitches together and analyzes disparate systems and data to yield greater insights and provides public safety personnel with additional critical tools that can anticipate, mitigate and resolve threats of all kinds more efficiently and effectively.

4.3 Digital Transformation

Dubai have set the infrastructure as a priority and enabler for economic development, wellbeing as well as safety and security of the community. The infrastructure as an enabler for safety and security is highly important not only for the city community but also for business and tourism. By using cutting-edge technology, traditional police stations in Dubai were revolutionized and automated. The SPS aim to help reduce customer visits to stations and government offices by 80 percent, and they will eventually be present in all residential and commercial areas of Dubai.

Digital Transformation is playing a fundamental role in shaping the way governments across the world are adapting to new opportunities and challenges. Dubai Police began this path more than 15 years ago applying different technologies in order to build a citizen's engagement and to combat the organize crime.

The digital transformation in Dubai Government is a result of a visionary leadership and full support by his Highness Excellence Sheikh Mohammed bin Rashid Al Maktoum is the Vice President and Prime Minister of the United Arab Emirates. The journey of digital transformation began in 1982 with the establishment of the Public Information Authority, with the aim of introducing computers into government work and automating government process and procedures.

In 2017, Dubai Police unveiled the strategic plan 2018-2031 for artificial intelligence (AI). The strategic will pave its way in accordance with the Dubai 2021 plan. The strategic plan of the Dubai Police aims to achieve the objectives to optimize and implement development programmes and projects relying on AI across all areas of police and to successfully serve the needs of the citizens of Dubai.

Dubai Police Strategic Plan, all the areas of police including security, traffic accidents, crime prevention, community engagement, forecasting of crime will be fully powered by artificial intelligence techniques. The aim will be at developing the best AI tools and techniques that will serve the people with better safety, locally and globally. SPS are using artificial intelligence in order to provide the best service to the citizens.

The Dubai Police always strives to set an example and bring about positive change. The idea of having an unmanned police station (and ultimately the SPS) evolved from years of enhancing police services while remaining aligned to the trend of the latest and state-of-the-art technology. It all began when mere paperwork in the offices of the Dubai Police began being digitalized; this was followed by the development of the Dubai Police Smart Phone App and gradually evolved to the “futuristic” idea of unmanned stations.

5. Discussion of the Results

After analyzing the main results of this case study through continuous improvement, innovation and digital transformation, here we discuss some of the main non-financial and financial benefit of SPS.

***Non-Financial benefits of SPS*:**

- The customer satisfaction reached 97.5% comparing with the same period in 2017 with 64.2% with average time for the transaction reduced from 22.32 Minutes to less than 5 Minutes and 71.0% decrease in traditional police station visitors in 2021 comparing with the same period in 2017.
- The initiative reduces the future SPS sizes (153,000 ft^2) in average to (1,100 ft^2).
- The initiative contributes towards reducing the workload so that services become more balanced: 80% (online) & 20% (traditional police stations) by having various and distributed SPS.

***Financial benefits*:**

- The SPS reduces the future Police Stations operational cost from US$2,2 Million to US$330.000 in average, and the cost of setting up Police Stations from US$30 Million to US$1.7 Million.
- Having a SPS will realise a cost reduction of traditional police stations. Target reduction of cost is about 90% per police station.

More autonomous police stations will be rolled out at later dates as part of the larger police strategy to provide smart police services to all residential and commercial areas. Having these services in the city not only will improve the law and order situation but also reduce the public’s time and effort.

Since 2017 more than 50 nationals and internationals police forces and law enforcement agencies had been doing benchmarking for best practices, learning from the SPS. We strongly believed that SPS can be implementing in any other city in the world. It´s not only about the strategy, technology, continuous improvement, innovation or digital transformation it´s also about the most important assets, people. In Dubai Police, we know that excellence happens only when people have a deeply felt sense of purpose in their lives. Employees want to know if they are making a difference, and are contributing to an important endeavor. That´s exactly what happens in Dubai Police; employees are making a real difference, with great contributions to the community and keeping Dubai one of the safest cities in the world, because Dubai Police give their employees a sense of purpose, help them feel they belong, and enable them to make a difference.

6. Conclusions

The success of Dubai Police highlighted in this article demonstrates the great potential for continuous improvement, innovation and digital transformation approaches in police forces and law enforcement agencies globally. What distinguishes Dubai Police journey of excellence is a complete and long-term commitment across the organization to ensure sustainability. The overall state of a building a culture of continuous improvement may be intangible. But the value of taking steps to shift Dubai Police toward a more quality-driven culture it had been substantial.

The SPS was launched the non-human interaction Police Station in order to help customers to have a great experience of digital transformation with Police services, but also to change the perception of the people and general public of Dubai with all the friendly services that SPS offers. During the pandemic SPS shows great results based on the number of people that used, 4,500 transaction in one month and regular police station less than 2,000 transaction, more than 60 types of services without human interaction.

SPS case study has implications for decision-makers in police agencies on how to build a continuous improvement, innovation and digital transformation at police forces and law enforcement agencies, but also how to improve their organizational performance using technology and the right strategy with a long term vision.

Dubai Police show in this study case that building understanding of those policing services by developing a close relationship with the community and citizens to prevent crime using the lasts technology it´s not enough. Dubai Police will continue improving SPS and others new technologies in order to personalized services and tailored approaches to harnessing community and organize crime prevention capabilities.

Continuous improvement, innovation and digital transformation are part of Dubai Police´s DNA. The Dubai Police will keep working hard in order to add value to Dubai´s residents, citizens and tourist. It is the journey, not the destination, that is important in striving for the quality services in the Dubai Police and sharing with all the stakeholders.

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8. References

Adderley, R. W., & Musgrove, P. (2001). Police crime recording and investigation systems– A user's view. *Policing: An International Journal of Police Strategies & Management*, 24(1), 100-114.

Agarwal, R., Gao, G.G., DesRoches, C. & Jha, A.K. (2010). The digital transformation ofhealthcare: Current status and the road ahead. *Information Systems Research*, 21(4),796–809.

Amit, R. & Zott, C. (2001). Value creation in e-business. *Strategic Management Journal*, 22(6–7), 493–520.

Al-Maamari, Q.A. (2020). The effect of Total Quality Management (TQM) practices on individual readiness for change with in yemeni oil units.

Bond, B.J. & Gabriele, K.R. (2018). Research and planning units: An innovation instrument in the 21st Century police organization. *Criminal Justice Policy Review*, 29, 67–88.

Colvin, C.A. & Goh, A. (2005). Validation of the technology acceptance model for police. *Journal of Criminal Justice*, 33(1), 89-95.

Custers, B. (2012). Technology in policing: Experiences, obstacles and police needs. *Computer Law & Security Review*, 28(1), 62-68.

Emsley, Clive, Reinke, Herbert & René Lévy (1994). Les polices au XIXe et XXe siècles: Aperçus sur les historiographies anglaise, allemande et française. Overview of English, German and French Police History Cahiers de la Sécurité Intérieure. IHESI, Paris, No.17, 13-33.

Gallup (2019). *Global Law and Order Report International Index*. Gallup USA Inc.

Garcia-Sabater J. & Marin-Garcia J. (2009). Enablers and inhibitors for sustainability of continuous improvement: A study in the automotive industry suppliers in the Valencia Region. *Intagible Capital*, 5(2), 183-209.

Garicano, L., & Heaton, P. (2010). Information technology, organization, and productivity in the public sector: evidence from police departments. *Journal of Labor Economics*, 28(1), 167-201.

George, N. (2005). *Hip Hop America*. Penguin Books.

Gölzer, P. & Fritzsche, A. (2017). Data-driven operations management: Organisational implications of the digital transformation in industrial practice. *Production Planningand Control*, 28(16), 1332–1343.

Harris, C. (2007). *Police and Soft Technology: How Information Technology Contributes to Police Decision Making*. In: Byrne, J. & Rebovich, D. (2007). The New technology of Crime, Law and Social Control, Monsey, NY: Criminal Justice Press, p. 153-183.

Hitpass, B., Román, J., (2020). Business Process Management Applied to Business Excellence & Benchmarking. Paperback, Amazon.

John, D. (1994). Civic environmentalism. *Issues in Science and Technology*, 10, 30–34.

Kaur, M., Singh, K., & Singh, D. (2019). Synergetic success factors of Total Quality Management (TQM) and Supply Chain Management (SCM). International Journal of Quality & Reliability Management.

Lersch, K.M. & Mieczkowski, T. (2005). Violent police behavior: Past, present, and future research directions. *Aggression and Violent Behaviour*, 10, 552–568.

Malik, S.A., Li-bin, L., YeZhuang, T. and Xiao-lin, S. (2007). Continuous improvement practices in Asian developing countries: a comparative analysis between Chinese and Pakistani manufacturing industry. Proceeding of the 14th International Conference on ManagementScience and Engineering, China, 692-697.

Matt, C., Hess, T. & Benlian, A. (2015). Digital transformation strategies. *Bussines Information Systems Engeneering*, 57(5), 339–343. https://doi.org/10.1007/s12599-015-0401-5

Maxwell, J.A. (2008). *Designing a qualitative study*. The Sage handbook of applied social research methods: 214-253.

Mergel, I. (2016). Agile innovation management in government: A research agenda. *Government Information Quarterly*, 33(3), 516–523.

Moore, M., Sparrow, M. & Spelman, W. (1997). *Innovations in Policing: From Production Lines to Job Shops*. In A. Altshuler & R. Behn (eds.), Innovations in American Government: Challenges, Opportunities, and Dilemmas. Washington, DC: Brookings Institution Press.

Karkoszka, T. & Roszak, M. (2005). Quality and environmental aspects in the technological process management. Proceedings of the Polish Conference on Projecting & Managing of the realization of the production, 63-68.

Lemon, K.N. & Verhoef, P.C. (2016). Understanding customer experience throughhout the customer journey. *Journal of Marketing*, 80(6), 69-96.

Lersch, K. M., & Mieczkowski, T. (2005). Violent police behavior: Past, present, and future research directions. *Aggression and Violent Behaviour*, 10, 552–568.

Li, L., Su, F., Zhang, W. & Mao, J.Y. (2018). Digital transformation by SME entrepreneurs: A capability perspective. *Information Systems Journal*, 28(6), 1129–1157.

Pillay, R. & Morris, M.H. (2016). Changing healthcare by changing the education of its leaders: An innovation competence model. *Journal of Health Administration Education*, 33, 393–410.

Rashid, F., Taib, C.A., Zien-Yusoff, R., Ahmad, M., & Hj, A. (2020). Human resources management practices and Total Quality Management (TQM) is the precondition to gain the sustainable competitive advantage in the bangladesh ready-made garments sector. human resources management practices and Total Quality Management (TQM) is the precondition to gain the sustainable competitive.

Reichert, K. (2001). *Use of information technology by law enforcement. Promising Approaches to Addressing Crime Series*. University of Pennsylvania, Jerry Lee Center of Criminology, Forum on Crime and Justice.

Roberts, N.C. & King, P.J. (1996). *Transforming public policy: Dynamics of policy entrepreneurship and innovation*. Jossey-Bass Incorporated Pub, San Francisco, CA.

Román, J. (2016). Six Steps to Building a Culture of Quality. Business Excellence Edition.

Román, J. (2019). Smart Police Station, Case Study. The Quality Management Forum, Quality Management Division. *American Society for Quality*, 45(1), 8-10.

Singh, A. & Hess, T. (2017). How chief digital officers promote the digital transformation of their companies. *MIS Quarterly Executive*, 16(1), 1–17.

Skolnick, J.H. & Bayley, D.H. (1988). *Community Policing: Issues and Practices Around the World*. Government Printing Office, Washington, D.C.

Tarafdar M., Monideepa D. & Robert M. (2018). Research in Information Systems: Intra-Disciplinary and Inter-Disciplinary Approaches. *Journal of the Association for* Information Systems, 19(6), 10-14.

Tombul, F. and Cakar, B. (2015). Police use of Technology to Fight Against Crime. *European Scientific Journal*, 11(10), 286 - 296.

Wright, S. (1978). New police technologies: an exploration of the social implications and unforeseen impacts of some recent developments. *Journal of Peace Research*, 15(4), 305-322.

Yin, R. K. (2011). *Applications of case study research*. Sage publications.

Yin, R. K. (2013). *Case study research: Design and methods*. Sage publications

Challenges and opportunities of collaborative robots for quality control in manufacturing: evidences from research and industry

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STRUCTURED ABSTRACT

Purpose - In the context of Industry 4.0, collaborative robots - which might be equipped with different types of sensors - have been gaining ground, used to cooperate with humans in quality control of finished or semi-finished products. Compared to the various applications of collaborative robotics in manufacturing (e.g., material handling, assembly, pick and place, and positioning), widely studied and adopted in industry, quality control and testing have not yet reached their full potential. This paper aims to study the state-of-the-art collaborative robotics used for quality control purposes in both academia and industry.

Design/methodology/approach – This paper analyses in a structured way the scientific literature and some prominent real industrial case studies regarding the state-of-the-art of quality control using collaborative robotic systems in manufacturing.

Findings - The analysis enables the identification and definition of the main challenges and opportunities that the manufacturing sector is facing for the large-scale use of the new quality control paradigm. Results show that collaborative robotics in quality still plays a marginal role and is mainly adopted for in-process visual inspections to increase system efficiency. Some barriers still hamper the full adoption of this paradigm, but there is plenty of opportunity for research and economic growth.

Originality/value - The innovative aspect of this research is the combined analysis of scientific articles and real-life case studies that provide a comprehensive overview of the research and actual use in industry of this emerging paradigm of quality control.

Keywords: Quality control, Manufacturing, Collaborative robots.

Paper type: Research paper.

INTRODUCTION

The application of Human-Robot Collaboration (HRC) in manufacturing systems has increased in the last years and goes hand-in-hand with the growing importance of Industry 4.0 related technologies. Collaborative robots (also called cobots) are defined as complex machines that support and relieve the human operator in a shared work process (Hentout *et al.*, 2019). Accordingly, in a simplified way, cobots are robots that collaborate with humans, sharing a workspace to alleviate human efforts. Drawing a parallel with the software context, cobots are the hardware version of augmented intelligence. Thus, instead of replacing humans with autonomous counterparts, cobots augment and enhance human performance with strength, precision and data capabilities to provide additional value to organisations.

The application fields of HRC are manifold and, as above mentioned, the main task is to relieve human workers from tedious and repetitive tasks, integrating the automation, repetitiveness, precision and flexibility that characterise collaborative robots while, at the same time, maintaining the cognitive and soft skills of human workers.

Product quality control is widely recognised as a key and indispensable factor in a production process that may reduce the number of defective parts reaching end-users (Montgomery, 2012). Considering the high customer demands in today's market, a constant search for new control systems and technologies to make quality control processes as efficient and effective as possible is one of the main challenges facing academia and industry.

In the context of Industry 4.0, cobots - which might be equipped with different types of sensors - have been gaining ground, used to cooperate with humans in quality control of finished or semi-finished products. Cobots are one of the key technologies of Quality 4.0*, i.e.* a new paradigm of quality management, which emphasises the need to adapt to recent technological innovations by updating traditional quality approaches in the modern era of Industry 4.0 (Antony *et al.*, 2021; Dias *et al.*, 2021). Quality 4.0 presents many benefits including real-time process monitoring, big-data collection and predictive maintenance supported by analytics (Küpper *et al.*, 2019). As a result, Quality 4.0 enables enterprise efficiencies, performance, innovation, and improved business models (Sony *et al.*, 2020). However, compared to the various uses and applications of collaborative robotics in manufacturing (e.g., material handling, assembly, pick and place, and positioning), widely studied and adopted in industry, quality control and testing still play a marginal role.

This paper aims to analyse the scientific literature and some prominent real case studies adopted by companies regarding the state of the art of quality control using collaborative robotics systems in manufacturing. The analysis enables the identification and definition of the challenges and opportunities that the manufacturing sector is facing for the large-scale use of the new quality control paradigm based on human-robot collaboration.

BACKGROUND FRAMEWORK

In recent years, the use of robotics has spread to almost every field and more specifically to the area of manufacturing, where the benefits that can be achieved are numerous. The underlying reason is that manufacturing today is facing the evolution towards Industry 4.0, which emphasises efficiency, cost reduction and productivity through automation and data analytics.

Industries, therefore, need to be faster, more flexible, proactive and respond quickly to market needs in a sustainable and efficient manner, ensuring excellent quality levels for customer satisfaction. The answer to these challenges has been partly found in the use of robotic automation within different production processes, playing a key role in the competitiveness of today's manufacturing industry. The main benefits of introducing robots into the production area include the ability to relieve workers of repetitive, heavy, and automatable tasks, as well as the resulting accuracy and repeatability, resulting in a higher quality product.

For high-volume manufacturing, a robot can maintain high efficiency and repeatability but lacks flexibility when it comes to problem solving and uncertainty. Human operators, on the other hand, know the way or can think of a possible way to solve these problems due to rationality, but they lack repeatability, speed and cannot lift heavy weights, which ends up in decreased efficiency and quality of the final product or service (El Zaatari *et al.*, 2019).

A balance between automation and flexibility is essential to achieve these overall manufacturing goals in mass customisation. This encourages researchers to look at combining the advantages of automation and manual labour. This research has culminated in Human-Robot Collaboration (HRC), a promising robotics discipline focused on enabling robots and humans to operate jointly to complete collaborative tasks (Zaatari, 2019).

This new area of research emerged during the fourth industrial revolution, or Industry 4.0, at the same time as the rise of the Internet of Things and the concept of collaborative systems. Shorter development times, customisation, adaptability and efficiency are all part of the Industry 4.0 paradigm. The smart factory is a concept introduced by the revolution, where everything is connected via sensors and computers, and large amounts of data are collected and evaluated for decision-making. Industry 4.0 and smart factories are two ideals that many industries are aiming for, and collaborative robots are a key aspect of both notions.

Collaborative robots make manufacturing lines more flexible and shift the status quo where robots and human operators are firmly separated; instead, they can now operate together and aim for the same goal. Collaborative robots can be integrated with numerous sensors and standardised interfaces and are designed to work together with humans and coexist in the same physical environment by enhancing, strengthening and assisting humans in increasing human well-being and production performance (Romero *et al.*, 2016). As a result, cobots were created and designed to work as pairs with humans in order to improve rather than replace their capabilities, thus representing a supporting technology towards Industry 5.0, where research and innovation are put at the service of the transition to a sustainable, human-centric and resilient European industry (European Commission, 2020; Maddikunta *et al.*, 2021).

Collaborative robots are increasingly preferred over traditional industrial robots as they can work in a variety of contexts and provide numerous advantages, including (*i*) ease of programming and program modification, making them more versatile and adaptable to various applications (*ii*) speed of setup (a few hours compared to weeks for traditional robots), (*iii*) flexibility, as they do not take up much space and can be deployed quickly, (*iv*) safety, being able to collaborate with humans without endangering them through the use of environmental cognition, and (*v*) equipped with sensors that detect various features. To summarise, collaborative robots are generally more profitable and productive than traditional industrial robots when used in the right situations. These robots are significantly lighter than industrial robots and, as a result, have greater mobility, making it easier to move them around the factory floor. The versatility of collaborative robots and their affordability make them a suitable choice for a wide range of industries and applications, including automotive, electronics, general manufacturing, metal fabrication, packaging and co-packing, plastics, food and agriculture, pharmaceutical and chemical, scientific research.

According to Statista's "Collaborative robots worldwide" research (Statista, 2022), sales and installations of collaborative robots worldwide increased from 11 to 18 thousands over two years (2017 to 2019). However, the collaborative robot market is currently a small part of the overall industrial robot market. In 2018, only 5% of the total robot unit sales worldwide were collaborative robots. However, the percentage is expected to become 13% by 2022. The prospects for the cobots market are bright for the next few years, indeed it is expected that the size of the global market for collaborative robots will grow from 590 to 1990 million U.S. dollars from 2020 to 2030 (Statista, 2022). The following are some of the reasons behind this expansion:

- lack of skilled labour, leading to a greater need for automation;
- rising labour costs, making robots cheaper than human operators;
- demand is becoming more complex, requiring higher product mixes with shorter cycle times;
- higher levels of efficiency are required.

Another reason not to be underestimated is the wide range of applications in which collaborative robots may be employed. In 2019, the revenue share of collaborative robot market by industry was as follows (Statista, 2022): electronics (34.1%), automotive (16%), semiconductors and FPD (8.3%), plastics and rubber (7.8%), food and beverage (7.6%), chemicals and pharmaceuticals (5.5%), logistics (3.9%), and other (16.9%). In 2022, the expected global market size of cobots by applications will be material handling (31%), assembly (23%), pick and place (13%), testing (6%), welding (5%), sorting (4%), positioning (3%) and other (15%). If the first three categories are aggregated, as they all involve handling and managing parts, a 67% market share is achieved. Indeed, cobots offer significant advantages when dealing with picking up heavy objects and performing precise assembly work repeatedly and efficiently, without the stress that a human operator would experience.

Alongside the interest of the market and industries, cobots are also gaining considerable attention in academia worldwide, as demonstrated by the exponential increase in the number of articles published since 2015, after the publication of the paper "Industry 4.0" (Lasi *et al.*, 2014), a pillar article that has undoubtedly brought much more popularity to the topic.

The above has shown the relevance that collaborative robots are gaining in industry and academia, and how they have the scaffolding to surpass traditional robots due to features such as flexibility, safety and efficiency. In this sense, it is crucial to continue researching and identifying new applications to benefit from. In addition, it has to be considered that nowadays there are not many manufacturers of cobots and that a small number of companies dominates the market. Hence emerges the need to expand the market, bringing more competition and innovations at a lower price, making the purchase of these new collaborative robots more accessible to SMEs that still cannot afford them.

RESEARCH METHODOLOGY

Scientific literature search

The general objective of this research is to perform an analysis of the scientific literature regarding the state of the art of quality control using collaborative robotics systems in manufacturing. The analysis enables the identification of the challenges and opportunities that the manufacturing sector is facing for the large-scale use of the new quality control paradigm based on HRC.

Literature search was performed in Scopus, Web of Science and IEE Xplore databases. A fourth source was also consulted, the open-source Google Scholar. Concerning the keywords, the following ones were used for collaborative robot topic: "collaborative robot*", "human-robot interaction", "human-robot collaboration", "human-robot cooperation", "robot* application", "physical human-robot interaction", and the following ones for quality control topic: "quality control", "quality", "quality inspection".

Although the growing popularity of collaborative robotics, the subfield of quality control application plays a marginal role. Only 21 results were found, and some of them are outside the scope of this paper. This highlights a gap, creating a potential new research field to cover in the coming years, considering the advantages and benefits of this specific application.

The final set of inherent articles includes the 12 documents summarised in Table 1.

Table 1 – Examined literature on quality control with human-robot collaboration.

Ref.	**Title**	**Year**	**Type of publication**	**Country**
Müller et al. (2014)	Inspector Robot – A new collaborative testing system designed for the automotive final assembly line	2014	Journal Article	Germany
Rooker et al. (2014)	Quality Inspection performed by a Flexible Robot System	2014	Conference Proceedings	Austria
El Makrini et al. (2017)	Design of a Collaborative Architecture for Human-Robot Assembly Tasks	2017	Conference Proceedings	Belgium
Pichler et al. (2017)	Towards shared autonomy for robotic tasks in manufacturing	2017	Conference Proceedings	Austria
Bruker Alicona (2019)	Non-contact and highly accurate measurement of critical turbine engine components	2019	White paper	Austria
Lopez-Hawa et al. (2019)	Automated Scanning Techniques Using UR5	2019	Journal Article	United States
Papanastasiou et al. (2019)	Towards seamless human robot collaboration: integrating multimodal interaction	2019	Journal Article	Greece
Syberfeldt and Ekblom (2019)	Improved Automatic Quality Inspections through the Integration of State-of-the-Art Machine Vision and Collaborative Robots	2019	Conference Proceedings	Sweden
Doltsinis et al. (2020)	A Machine Learning Framework for Real Time Identification of Successful Snap-Fit Assemblies	2020	Journal Article	Greece
Brito et al. (2020)	A Machine Learning Approach for Collaborative Robot Smart Manufacturing Inspection for Quality Control Systems	2020	Conference Proceedings	Portugal
Karami et al. (2020)	A Task Allocation Approach for Human-Robot Collaboration in Product Defects Inspection Scenarios	2020	Conference Proceedings	Italy
Jian et al. (2021)	An image vision and automatic calibration system for universal robots	2021	Journal Article	Taiwan

The distribution of documents per year and per country is reported in Fig. 1.

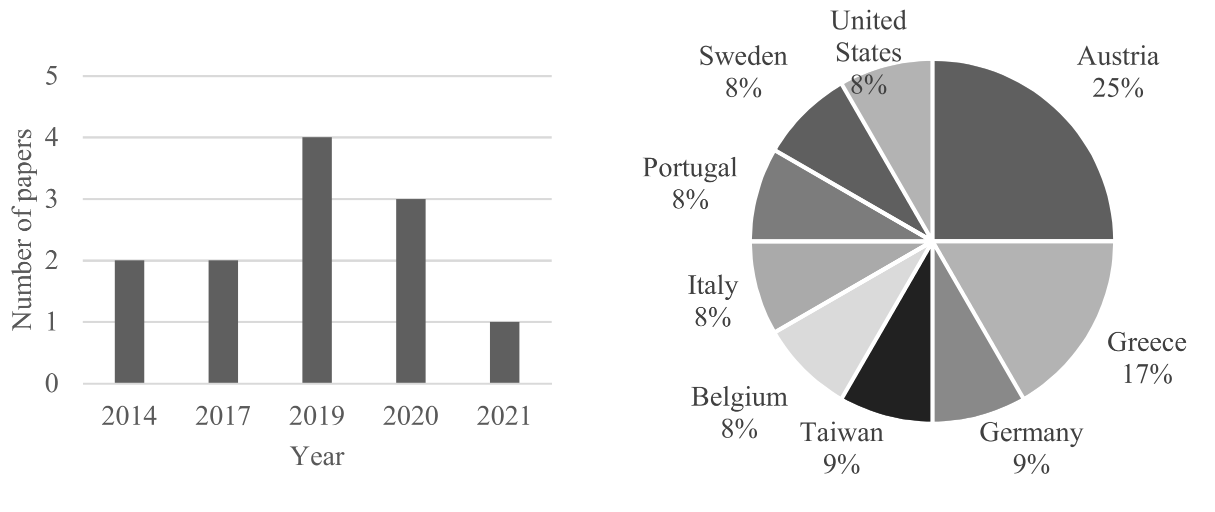

Figure 1 – Distribution of examined literature on quality control with human-robot collaboration per (a) year and (b) country.

Note that no papers are dated before 2014, while until 2021 the number of articles has remained nearly constant with a peak in 2019. This highlights how research regarding the use of HRC for quality control and inspection processes has increased with the emergence of Industry 4.0, but not exponentially as for HRC in general.

Regarding the country, the country-of-origin of the examined literature was attributed according to the country of affiliation of the first author of each paper.

Although the number of articles is very small, it can be noted that the origin is diversified and not concentrated in a few countries, as is the case for general research on cobots, where United States, Germany, Italy and China have the primacy (source Scopus). Finally, half of the articles have been published in conference proceedings, showing how research in this area is still in its early stages, and the results are not yet fully mature for publication in peer-reviewed journals.

Real case studies search

In order to provide a broader understanding of the topic, other sources of information were sought, considering real case studies. To this end, the web pages of collaborative robot manufacturers were analysed. In particular, the webpage of Universal Robots™ (UR) was primarily used for the wide range of case studies available, only considering case studies within the scope of this paper, *i.e.* concerning quality control (Universal Robots, 2022). Universal Robots™ is a pioneering company that has been working in the collaborative robot industry since 2005, but only in 2008 their first collaborative robot was launched into the market.

Table 2 summarises the examined case studies regarding quality control using HRC in which cobots by UR were employed. For each case study, Table 2 reports the primary information about the company (country, industry and company size), the description of the quality control process before the adoption of HRC, the challenges and requirements of adopting the new control paradigm.

Table 2 – Real case studies on quality control using HRC - general framework (Universal Robots, 2022).

Company	**Country**	**Industry**	**Company size**	**Process before HRC**	**Challenge**
BÖCO BÖDDECKER	Germany	Automotive and subcontractors	400	Each part is individually marked with a code and quality control is done manually	Increase efficiency by identifying repetitive tasks. Each part must be individually marked with a code
BW INDUSTRIE	France	Metal and machining	45	Manual inspection	Save from relocation. Increase competitiveness and reduce strenuous works tasks
COMPREHENSIVE LOGISTICS	USA	Automotive and subcontractors	190	Manual inspection, 80% efficient. The company's stationary multi-camera system could not position cameras into tight spots and was not as repeatable as the manufacturer needed. The data gathered by the camera system were not as pure	Life-threatening failure mode components, important to make sure that the clips are locked into place with 100% confidence
CRAFT AND TECHNIK INDUSTRIES (CATI)	India	Automotive	80	Most manufacturing tasks were handled manually	No availability of qualified manual labour, need to reduce the customer rejections for faulty components. No space
EVCO PLASTICS	USA	Plastics and polymers	300	Manning cells with repetitive and tedious tasks, handling parts assembly, machine tending, and packaging was especially hard. Operators prone to forget steps in the assembly process	Fast-changing processes. Low unemployment and trouble staffing the third shift in the company's 24/7 production
FERDINAND WAGNER	Germany	Metal and machining	90	Between 500 and 600 thousand components were manually soldered and welded each year, no longer cost-effective. Fluctuating manual production	Need of a robust and dependable automation solution that could consistently deliver high-quality welding and soldering of fragile parts
FORD MOTOR COMPANY	Romania	Automotive	5000+	-	Solutions to enhance their manual workforce generating added value to the manufacturing process
GKN DRIVELINE	Japan	Automotive and subcontractors	1400	Old machines, called front and back discriminators, were insufficient, so line workers were asked to manually perform such inspection tasks after a long workday	Chronic labour shortage issue. Difficulty of automating the experience and sense the operators as well as the safety issue with the traditional machinery

IZOELEKTRO D.O.O.	Slovenia	Electronics and technology	8	Manual time-consuming process	Increase production and improve quality assurance. Fulfil customers' demands in a cost-efficient manner
KOYO ELECTRONICS INDUSTRIES	Japan	Automotive	343	Manual product assembly and visual inspection, and in the post-process, operators apply styluses to the touch panels to confirm the devices react as intended	Increase productivity according to increase in demand in the production of products that require strict quality
NORDIC SUGAR	Sweden	Food and agriculture	1430	During the production season, the testing department analyses 80 thousand sugar beet samples. Robots have performed the task of weighing in containers with pureed beet since 1993. Expensive specialists to make a change. Too costly	Technological advances within robotic arms meant that it was time to replace the old ones
OPTIPRO SYSTEMS	USA	Metal & machining	70+	-	Automated solution that could measure in-process the products. Quality control is crucial since most OptiPro customers manufacture parts for the medical and military sectors requiring 100% inspection
STELLANTIS	Italy	Automotive and subcontractors	407500	No previous state because it is new assembly line	Assembly processes and quality controls required introducing specific automation technologies to ensure the quality and repeatability needed to meet product standards
THYSSENKRUPP BILTEIN	USA	Automotive	700+	Manual check of two parts every one or two hours	Increase in customer demands combined with fast-changing product requirements. Keep its manufacturing processes lean and flexible and could not grow at the desired rate by simply hiring more people

RESULTS

Analysis of the examined literature

In this section the examined literature is analysed focusing on the quality control performed. Especially, two different quality control paradigms are considered: in-process controls and offline controls. The main difference is that in-process controls are performed during production, while offline controls are performed at the end of production once the product is finished. As a result, in-process quality controls may enable that non-conforming parts do not reach the end of the line and, accordingly, defects can be reworked/scrapped directly during the manufacturing process, with possible consequent reductions in waste compared to offline controls (Genta *et al.*, 2020). Both in-process and offline quality controls are carried out using different types of inspections, *e.g.* visual or manual inspections, dimensional measurements, conformity tests, etc.

In Table 3, each examined document is classified according to the following analysis dimensions, defined by the authors:

- Industry: if available, industry field of the research.
- Process: typology of manufacturing process.
- Objective: aim of the quality control.
- Paradigm of quality control: general framework, in-process or offline controls.
- Type of inspection: typology of inspection (manual, visual, dimensional measurement, etc.)
- Methodology: research methodology/approach used.
- Technology: technology used for the control.
- Communication channel: kind of communication between human and cobot.
- Pros/Novelty: innovative aspects of the research.
- Research insights: possible research next steps.

For fields not specified, the symbol "-" is used.

Table 3 – Classification of examined literature on quality control with human-robot collaboration.

Ref.	Industry	Process	Objective	Paradigm of quality control	Type of inspection	Methodology	Technology	Communication channel	Pros/Novelty	Research insights
Müller et al. (2014)	Automotive	End-of-line car final inspection	Water leak test on a final assembly line inspection	Offline	Visual	-	Thermographic camera	-	The robot is mounted on a linear track and guided alongside the assembly object	Integrate this process into a real industry case. Apply it to other kinds of inspection processes.
Rooker et al. (2014)	Automotive	-	Examine the interlocking of plugs	In-process	Visual	Structured light principle	RGB-D sensor, ReconstructMe ShapeDrive® Sensor	Hand-guided	3D-sensor for the data acquisition is independent of the surrounding light conditions.	Introduce a more complex inspection process
El Makrini et al. (2017)	-	Assembly of a box	Put the assembly components in the correct order and perform quality control afterwards	In-process	Visual	Hough transform	Kinect v2 camera. Middleware NiTE 2.2, IAI Kinect2 ROS package. Hough transform provided by the OpenCV library	Face and gesture	Quality control during the assembly process. Gesture recognition and face recognition. Human-robot behaviour by providing social cues such as head nodding/shaking and eye gaze	Integrate this process into a real industry case. Introduce a more complex inspection process
Pichler et al. (2017)	Automotive (Engines)	Engine assembly	Quality inspection process for generator-plug connectors in car engines	In-process	3D Object Recognition	Random Sampling Algorithm	XRob software, 3D sensors, software ReconstructMe	Skeleton tracking (Gestures)	Environment reconstruction	Introduce a more complex inspection process. Test a collaboration environment
Lopez-Hawa et al. (2019)	-	Line scanner for scanning inspection	Generate surface geometry for further inspection	Offline	Surface characterisation	Test Object Grabbed by Robot (TOGR)	Keyence line scanner, combination of Ethernet socket communication and USB connections	-	MATLAB user interface to simulate the process	Integrate this process into a real industry case. Introduce a real inspection process. More cloud points and calibrations are required for the full construction of the object
Papanastasiou et al. (2019)	White goods	Pre-assembly of the refrigerator's cabinet	Improve sealing operation	General framework	-	-	Force/torque sensors, microphones, cameras, smartwatches, AR glasses, vision system, force sensors or joysticks attached to the robot, air press sensor	Speech, Gestures, Force measurement and mechanical	Top-level communication technologies	Integrate this process into a real industry case. Speed up the robot motion in safety mode. Test the network for an inspection process

Syberfeldt and Ekblom (2019)	Volvo Group Truck Operations (Engines)	Apply two strings of glue on a frame to mount the engine cover	Determine if the glue strings are correct or not	In-process	Visual	Machine learning	Machine vision system, wrist camera	-	Machine learning	Evaluate the precision of the automatic quality control system developed and compare its performance with the manual inspection process
Bruker Alicona (2019)	Aeronautic components	Measurement process	Measurement of critical components of turbine engines	In-process	Surface characterisation	Fire Variation	Visual sensors	-	Measurement technology is directly integrated into production. Sensors detect defective components, and this information is automatically fed into the production cycle.	-
Brito et al. (2020)	-	Quality inspection tasks	Carry a product to be inspected in a given position	Offline	-	Reinforcement Learning	Force-Torque sensor FT-300, cone-shaped 3D printed tool	Operators apply force to a Force-Torque sensor that sends information to the system	Machine learning for reinforcement learning	Integrate this process into a real industry case
Doltsinis et al. (2020)	-	Snap-fit assembly	Characterisation and inspection of snap-fits	In-process	Force signal characterisation	SNAP-FIT FORCE SIGNATURE and Machine learning	A 7-DOF KUKA LWR 4+ manipulator with the three-finger gripper Barret BH-8. KUKA force estimation mechanism without using an external force sensor	Through Force measurement	Machine learning	Integrate this process into a real industry case. Apply it to other kinds of assembly processes
Karami et al. (2020)	-	Defect inspection on a product	Inspection of product defects	Offline	Visual	AND/OR graphs	Dual-arm Baxter manipulator from Rethink Robotics and a Kuka youBot mobile manipulator. LG G Watch R (W110) smartwatch	Gesture	AND/OR graphs for activity programming	Integrate this process into a real industry case. Introduce a real inspection process
Jian et al. (2021)	-	Grab and place	-	General framework	-	Hough transformation	Image vision and automatic calibration system. 2 CCD camera, computer and a robotic arm	-	Find an object on an image. Accurately locate the mass point of the workpiece to be gripped	Integrate this process into a real industry case

Analysis of examined real case studies

The previous section presented the state of the art of published papers on quality control with human-robot collaboration systems. However, the set of papers that suit the purpose of this article is scarce and half of these lack a real case application in industries. The plausible reason could be that being a topic of recent research interest, the approaches and methodologies developed have not yet been fully adopted or validated in real industrial applications of quality control processes with collaborative robots.

In Table 4, the descriptions of the main features of the solution adopted by each company are summarised. In particular, the analysis dimensions for each company, identified by the authors, are the following:

- Solution: description of the adopted solution.
- Main benefit: description of the main advantages achieved by the new solution.
- Technology used for control.
- Paradigm of quality control: in-process or offline paradigm of control.
- Type of inspection: typology of inspection (manual, visual, dimensional measurement, etc.).
- # Robots: number of robots adopted in the solution (single or multiple, see Wang *et al.* (2019)).
- # Humans: number of humans/operators involved (single or none, see Wang *et al.* (2019)).
- Robot role and Human role. Roles may be (*i*) active, meaning leading the task, or (*ii*) supportive, performing auxiliary tasks and assisting the other agent, or (*iii*) inactive, with no responsibility on the task, and meaning an obstacle to the other agent (Wang *et al.*, 2019).

For fields not specified, the symbol "-" is used.

Table 4 – Real case studies on quality control using HRC - collaborative solution features (Universal Robots, 2022).

Company	HRC Solution	Main benefit	Technology used for control	Paradigm of quality control	Type of inspection	# Robots	# Humans
BÖCO BÖDDECKER	The UR robot marks and label items to the strict requirements while doing quality control checks. The robot also identifies and discards faulty parts with camera control system. The camera can objectively determine the quality of the part.	Reduces likelihood of faulty parts being sent to customers.	6-axis robot arm with five kg lifting capacity. Advanced camera control system	In-process	Visual	Single	-
BW INDUSTRIE	Cobot presents metal tubes in front of two high-definition cameras which inspects the dimensional characteristics of the extruded tubes. If the inspection fails, the cobot places the part in a reject box.	Keep production in France. Maintain competitiveness and increase its workforce by 50%. Revenues increased by 70%. Reduction of the risk of musculoskeletal disorders (MSDs) among employees, Ensuring a healthier working environment. ROI less than 12 months.	High-definition cameras	In-process	Dimensional measurement	Single	Single
COMPREHENSIVE LOGISTICS	Cobot moves a vision camera safely and repeatably between inspection points, snapping a picture of each connection. If the inspection fails, operator can go in and re- inspect just the failed portion of the cycle. Each image processed and inspection results shown on a screen next to the cobot.	ROI of 7 months.100% quality in the assembly of automotive engines. Zero maintenance with no downtime or interruptions of the line.	Vision camera	Offline	Visual	Single	None

CRAFT AND TECHNIK INDUSTRIES (CATI)	Cobot places a component on a weighing machine, takes feedback via digital input to decide whether the part meets its weight requirement or not, and then proceeds to sort the component accordingly.	Efficiency has increased with production volume going up 15–20% with no defects or customer rejections.	Weighing machine	Offline	Weight measurement	Single	None
EVCO PLASTICS	After the cap is successfully inserted, the UR5 places the gearbox on a scale to make sure the grease has been added. If the gearbox does not weigh the correct amount, the UR5 places it in a reject box Like the UR5 in the assembly cell, the UR10 on the packaging line also uses force/torque sensing: first to check that all four corners of the box are where they're supposed to be, and second to place cardboard sheets between each layer of parts in the box.	Total costs allocated over several customers, so that makes them cost-competitive.	-	Offline	Weight measurement	Single	None
FERDINAND WAGNER	Robot takes the piece to a high-frequency soldering station to be fused together. The robot then holds the pieces up to a camera system that automatically and objectively checks the quality of the welding and soldering work. They are used in two-shift intervals followed by a blind shift. At the end of the working day the robots continue working on an unmanned shift until the material is exhausted.	Employees now mainly focus on the processing of smaller batch quantities. Improved the operational efficiency of the production line. This robot duo is designed to process around 160 parts/hour.	Camera system. Robots and the gripping tools are fine-tuned to carefully move the parts as they have fragile decorative surfaces, and any damage renders them unusable	In-process	Visual	Single	None

FORD MOTOR COMPANY	Checking the engine with a UV light and a camera for leakage after it has been filled with oil.	Faster production throughput while also relieving employees of repetitive tasks. Cobots do not require human/operator's intervention unless a change occur in the usual processes.	Cognex camera vision, a UR+ product, communicating with the cobot through Ethernet	In-process	Visual	Multiple	-
GKN DRIVELINE	Two UR5 were introduced to the front and back inspection process of a thin iron plat. An external high precision camera judges if the plate is in the right side or not.	Manufacturing under a full 24-hour operation. Safe space-saving. No more risk of worker fatigue.	External high precision camera. Zone sensors are set in 4 different directions, which sets the robot in slower motion when people are around	Offline	Visual	Multiple	Single
IZOELEKTRO D.O.O.	The first project included two operation tasks as product routine testing processes for low voltage surge arresters and medium voltage surge arresters where the robot was applied. A future application is to include product routine testing of tensile load for tension composite insulators and post line composite insulators.	A robot can work for eight hours straight in one shift with consistent efficiency. The production and testing time of each product is much faster, reducing the overall production cost as human errors are eliminated. ROI between 18 and 24 months.	-	Offline	Conformity/ functionality test	Single	None
KOYO ELECTRONICS INDUSTRIES	UR3 touches the touch panel with a stylus, "OK" is displayed if there is no quality error, and the green signal of a signal tower lights up. When an abnormality is detected, "NG" is displayed on the display, the red signal tower lights up, and the buzzer sounds continuously. As a result, the person in charge immediately notices the abnormality and can respond.	Quality of the work improved. No interruptions in production. Reduced the daily work time from an average of 10 hours to 8 hours. 31% increase in productivity. ROI of just 1 year. Allocating human resources to another process.	Stylus	Offline	Conformity/ functionality test	Single	Single

NORDIC SUGAR	The UR5 robots scan barcodes and pick up containers with sugar for analysis from scales to filters and back again.	No longer have to call expensive experts when they need to change a robot's task. Payback period: 124 days.	Barcodes scanner	In-process	Weight measurement	Multiple	None
OPTIPRO SYSTEMS	When parts come out of an OptiPro grinding machine, Q-Span® Workstation immediately measures the parts in a pass/fail scenario. If parts pass, they move on to the CMM machine for further measurement.	Catch out-of-tolerance issues right away and change drills or feed rate if need be. Avoid brittle material breaking and sharp edges getting fractured or chipping from manual handling reduced in-house workforce.	-	In-process	Dimensional measurement	Single	Single
STELLANTIS	Visual inspection to ensure the correct extrusion of the adhesive band around the perimeter. Check on soft-top frame dimensions. Vision system checks the geometric continuity and dimensions of the adhesive band. UR cobot runs a size check (through a vision system) on the soft-top frame to ensure the conformity of the dimensions. Once conformity has been ascertained, the soft-top is removed from the line by the anthropomorphic robot.	Operating precision and quality, and also improved the ergonomics of a series of operations previously performed manually.	-	In-process	Dimensional measurement	Multiple	-
THYSSENKRUPP BILTEIN	Gauge inspection and check the post-fill crimp and final parts assembly. The cobot deployed in the final assembly is equipped with a Cognex camera and moves swiftly between inspection points to make sure that all components are in the right position and that the label is applied correctly and is readable.	10-14 months ROI. Product quality increase as a result of 100% inspection. Zero maintenance with no downtime or interruptions of the line. Elimination of repetitive and ergonomically unfriendly workflows. Employees alleviated from ergonomically unfavourable tasks.	-	Offline	Visual	Single	None

CHALLENGES AND OPPORTUNITIES

In this section, the challenges and the opportunities that the manufacturing sector will face for the large-scale use of the new quality control paradigm based on human-robot collaboration are be presented, based on the analysis results discussed in the previous section. In this study, challenges and opportunities refer to a specific *i*-th dimension, and are labelled as follows:

- C*i.j*: challenge corresponding to dimension *i*, order *j*.
- O*i.j*: opportunity corresponding to dimension *i*, order *j*.

Six dimensions were identified and considered, as follows:

- Dimension 1: Type of quality control.
- Dimension 2: Visual inspection.
- Dimension 3: Safety and trust in the collaborative system.
- Dimension 4: Efficiency of the collaborative system.
- Dimension 5: Fear of human job replacement.
- Dimension 6: Economic growth.

<u>Dimension 1: Type of quality control</u>

O1.1: Towards in-process controls

The pie chart in Fig. 2 shows the distribution of examined literature and actual case studies between in-process and offline quality control paradigms.

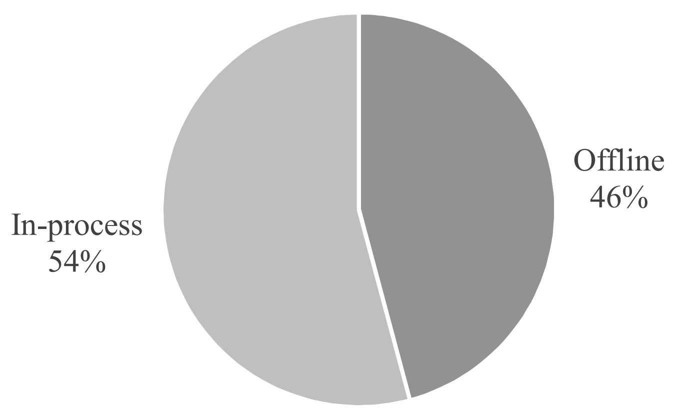

Figure 2 - Distribution of type of quality control of examined literature and case studies.

These two categories appear to be almost equal, with a slight predominance of in-process controls. As abovementioned, in-process controls are quality control performed during production to prevent defective parts from reaching the end of the line (Genta *et al.*, 2020). In this view, researchers and industries need to continue on the path towards in-process inspections. Collaborative robots support this policy by being small, lightweight, and flexible. Cobots require little space and are suitable for embedding into existing production lines. As a result, the space required for offline controls is not needed, and the resources that these extra stations would require are also saved. This implies an opportunity to make production systems more efficient in terms of cost and time savings and, more in general, to bring significant advantage for today's competitive market.

O1.2: Expanding the fields of application

Fig. 3 shows the types of inspections mentioned in the examined literature and in the real case studies analysed.

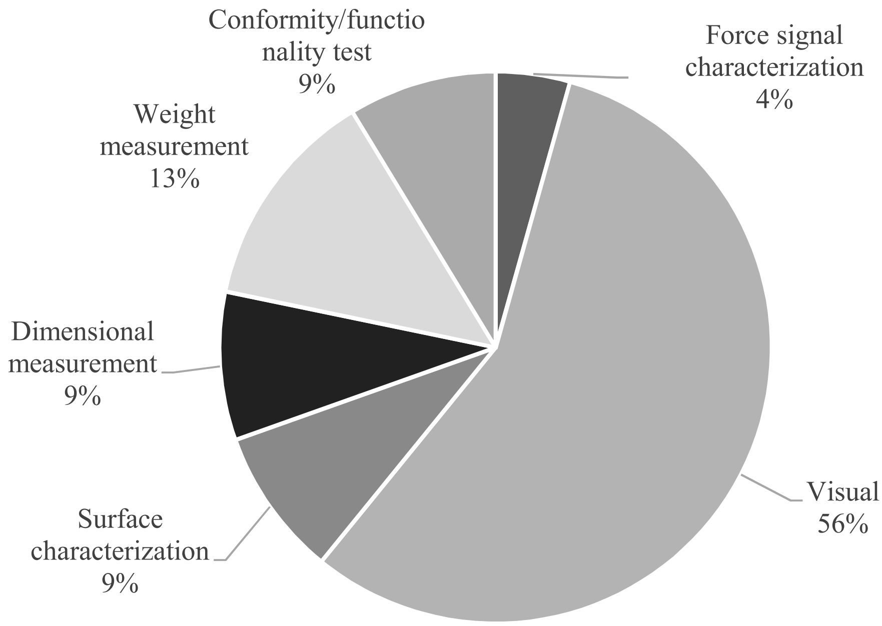

Figure 3 – Distribution of type of inspections performed on examined literature and case studies.

Visual inspections are the most frequently addressed type of inspection in both industry and academia (56%). Indeed, visual inspections previously performed by operators can be easily replaced by mounting a camera on the arm of the cobot, whose learning capability may be improved by using machine learning techniques. As Fig. 3 shows, there is plenty of scope for development and research into other types of inspection performed by cobots, including dimensional and weight measurements, topographical and mechanical characterisation and conformity or functionality testing.

C1.1: Application on real industrial cases

As the literature review showed, there is often a lack of real application of the quality inspection methods developed in the studies. The challenge for researchers is to test the functioning of the developed systems in real applications. Thus, in the future, comparisons can be made between manual and collaborative quality control, testing in which cases and conditions the collaborative scenario is more advantageous.

Dimension 2: Visual Inspection

A specific dimension is dedicated to visual inspection, as it is the most widespread application of cobots in the field of quality control.

C2.1: Ensuring accurate visual inspection

Although equipping the cobot with a camera may seem straightforward, visual inspection is not trivial to implement in industrial environments. For example, Lopez-Hawa et al. (2019) state that a problem encountered during scanning was an error in the data generated due to the reflection of the laser beam. This error increases with an increase in the reflectivity of the object being used, thus methods to eradicate or minimise this problem require further research. Syberfeldt and Ekblom (2019) claimed that even on low-quality images, object detection becomes complex. It is difficult in an industrial environment because the content of the image could vary greatly depending on the product variant or the angle from which the image is taken. When there are randomness and disturbances in the images, it becomes difficult to achieve accurate feature recognition for object location. How to handle this challenge efficiently is an open question that requires further study (Syberfeldt and Ekblom, 2019). Therefore, the challenge is to ensure similar conditions throughout the inspection process so that the system conditions may be considered stable and provide accurate information. However, this is not straightforward considering the intrinsic variability of industrial environment. The above-mentioned issues related to visual inspection represent a barrier to the flexibility that characterises cobots.

C2.2: Training the visual system

Many of the authors applying visual inspection have also equipped their systems with machine learning algorithms as they make the system able to learn and refine itself as more inspections are performed. This results in a more accurate and precise inspection system. However, the performance is dependent on rigorous training and appropriate training data, which in this case are images (Syberfeldt and Ekblom, 2019). The challenge is to provide the system with as many images as possible. Two categories of images must be provided for training the system:

1. Images that correspond to a conforming part.
2. Images that correspond to nonconformities.

The more complex the inspection task, the more training data is needed. In particular, the system needs as many images as possible related to nonconformities to recognise all possible cases in which parts should be rejected. However, it is not possible to provide the system with 100% of the possible non-conformities due to high process and product variability. Therefore, inevitably a small percentage of cases will always occur wherein the system will not be accurate in recognizing and acting accordingly.

O2.1: Overcoming light issues

One solution presented by Rooker et al. (2014) to solve the surrounding light challenge is using a blue-light LED projector and a suitable blue light bandpass filter. Incorporating the cobot with own light that provides the right conditions to perform an accurate visual inspection allows a portion of the challenges presented in C2.1 to be overcome. As a result, this is also an opportunity to expand visual inspection applications using cobots in manufacturing systems.

Dimension 3: Safety and trust in collaborative system

C3.1: Safety assessment

Safety is a vital topic when dealing with human-robot collaboration. In order for the operator to trust the robot, the operator safety must be ensured. However, the authors of the analysed papers do not pay particular attention to system safety evaluation. The underlying reason may be that some research is in a preliminary study phase, and the application has not yet been thoroughly implemented and tested in a real-world scenario. However, as Andersson et al. (2020) affirmed, if safety is not assessed in the pre-study, it may propagate into the following stages of implementation. Thus, the manufacturer needs to adapt the collaborative robot application in subsequent stages to ensure safety, which may impact the application's design (Andersson *et al.*, 2020). The challenge for future research is to implement safety assessment from the early stages as, if this is not incorporated, it can be a barrier to later-stage implementation.

C3.2: Collaboration instead of Cooperation

As shown in Fig. 3, in none of the case studies analysed, the human operator plays an active role.

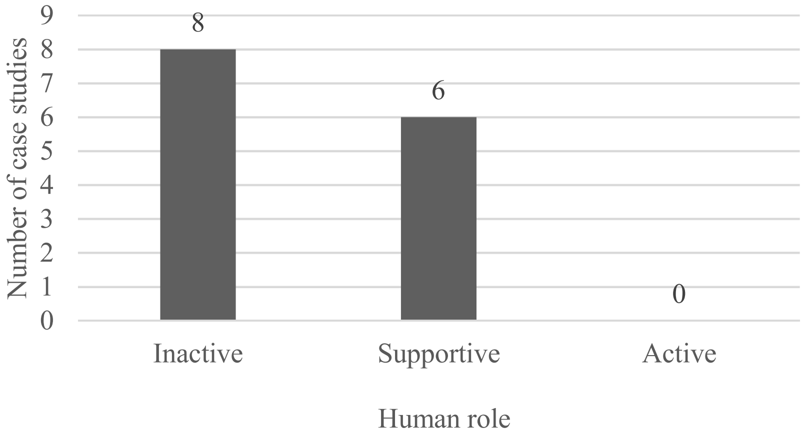

Figure 4 - Human role in the collaborative system in the analysed case studies.

Therefore, no real collaborative scenario has been identified in today's production processes, but rather cooperation, where cobot and operator work together for mutual benefits, albeit each one has its own goal. The workspace and resources are shared in a sequential and even simultaneous process. The work is divided into subtasks, which are then assigned to operators and robots respectively, and each is responsible for its part of the work. Analysing real case studies, the role of the operators is only to control or support the robot, assist it when a problem arises, or provide material to work with. No tasks are shared between the human and the robot. Certainly, cooperative systems also imply benefits for the quality control process, yet the challenge is to increase collaborative applications in which effective collaboration occurs.

O3.1: Human-Robot Communication

The opportunity to develop more human-robot collaborative systems is closely related to how humans can communicate and interact with the cobot. As presented in the previous section, several channels can be used to enable communication between the human and the cobot. In Fig. 5, the communication channels in the examined literature on quality control in human-robot collaborative systems are represented with the corresponding number of papers.

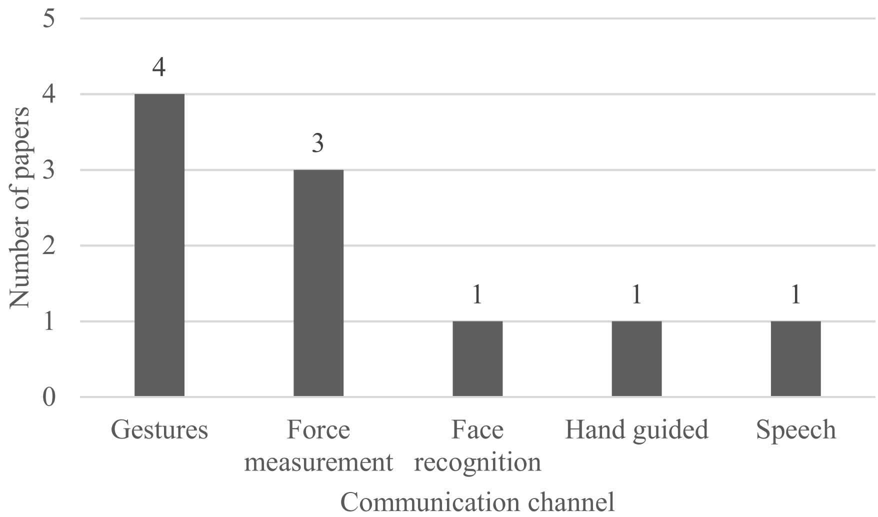

Figure 5 – Number of papers per communication channel used on examined literature.

In addition, communication helps to ensure a safe environment for humans. If the robot can understand human gestures and speech, collaboration tasks are performed more naturally, and the cobot is able to know how to respond accordingly to human movements, words and actions. Research related to human-robot collaboration also revolves around enhancing particular enabling functions such as visual perception and action recognition that enables human awareness and promotes flexible cobot behaviour (Knudsen and Kaivo-Oja, 2020; El Zaatari *et al.*, 2019). Many of the examined papers do not mention the communication between humans and cobots. However, if communication is not addressed in the early design stages, it can become a critical issue during the actual implementation of the quality control process. Researchers and manufacturers using cobots for quality control processes have an opportunity to equip the robots to make communication between agents as natural as possible for humans. Despite the increasing use of gestures and voice commands in HRC to control robots, they are less natural or practical in crowded and noisy work environments. Instead of defined gestures and voice commands, recognising and predicting human movements through deep learning provides better context awareness and fewer disruptions to typical performance induced by signalling gestures (Wang *et al.*, 2019).

O3.2: System parameters adaptation

If the system is already embedded with visual capabilities, e.g., with a camera, the system can be improved and made more personalised and safer for the operators by adapting the robot's behaviour to the user. Parameters adaptation can be quickly done after recognising the operator's face, and with a database provided to the cobot the height of the person can be extracted, and consequently, the speed and height at which the parts are given can be defined (El Makrini *et al.*, 2017). Although a vision system is not present, this feature can be added to the process by providing a username and password to each operator. If the system is customised for each operator, humans would have more confidence in it and environment safety would be more guaranteed as the speed of work adjusts to different operators.

Dimension 4: Efficiency of the collaborative system

O4.1: Overall efficiency and costs reduction

The adoption of collaborative robots to quality control processes has increased the efficiency and productivity of production lines and led to a reduction in costs, as experienced by companies reported in Tables 2 and 4. Moreover, the ROI of collaborative robots is very promising, as it ranges from months to a maximum of two years (Universal Robots, 2022).

O4.2: Reduce human error

Another benefit that industries have found by applying cobots to quality control processes is the reduction of human error, and thus improved defect detection, shorter production and testing time, and greater end-customer satisfaction. Reducing the incidence of errors and increasing the defect detection capability is crucial in the quality control processes of current manufacturing systems.

Accordingly, the opportunity to improve these aspects through collaborative systems must be considered to be competitive.

Dimension 5: Fear of human job replacement

C5.1: Human fear of losing job

Operators often associate the introduction of robotic technology with the fear of being replaced by machines (Kopp *et al.*, 2020). Therefore, the challenge is to let operators know that the introduction of cobots does not imply that they will be replaced, but instead that they will be reassigned to other tasks involving more cognitive and reasoning efforts, adding more value to the company. The goal is to make humans feel that the cobot is like a human colleague, that it is safe to work with, and that it relieves them of tedious tasks.

O5.1: New tasks for humans

As was explained in challenge C5.1, by incorporating collaborative robots into production lines, humans can be reassigned to more valuable tasks where they can apply reasoning and bring more value to the process. On automotive assembly lines, where many quality checks are performed, there is a clear opportunity to assign repetitive, automatable control to robots, and more skilled tasks to human operators (Müller *et al.*, 2014). This is possible by making human operators feel more useful and assigning them tasks that are not boring and stressful.

Dimension 6: Economic growth

O6.1: Cobot market growth worldwide

The development of the market in terms of both suppliers and demand can affect what will become the dominant type of cobots as well as the dominant cobot markets (Knudsen and Kaivo-Oja, 2020). As the cobot market expands, supply and demand will change, resulting in a price decrease. With a more affordable cost, applications of cobots on production lines will experience an increase and small companies will be able to afford the investment to purchase them.

CONCLUSIONS

The introduction of collaborative robots in the quality control process is growing in importance in recent years. Collaborative robots are flexible, fast, lightweight, and work flawlessly with human operators. A distinguishing feature of collaborative robots for inspection processes is repeatability and accuracy. They can repeat the inspection procedure many times, without needing to stop, 24 hours a day, and they will do it the same way, making the process more capable of detecting non-conformities. This type of inspection activity is often more prone to errors when performed by humans, which is why the introduction of collaborative robots is beneficial. The use of collaborative systems also implies increased motivation of human operators, being aware that the robot performs repetitive and automatable tasks and can focus on tasks that require human reasoning to perform. For example, most of the applications involving cobots are visual inspections, where vision sensors or cameras are integrated into the cobot to inspect different visual aspects, such as size, shape, presence of an object, etc., with accuracy and precision.

In the present article, the scientific literature dealing with HRC in industrial quality control was analysed. In addition, some real-world case studies were investigated to understand the state-of-the-art in the industrial domain. The analysis of the articles and case studies led to the definition of 6 dimensions of analysis. Each dimension was then divided in turn into challenges and opportunities that the manufacturing sector will face for the large-scale use of this new control paradigm, summarized in Fig. 6.

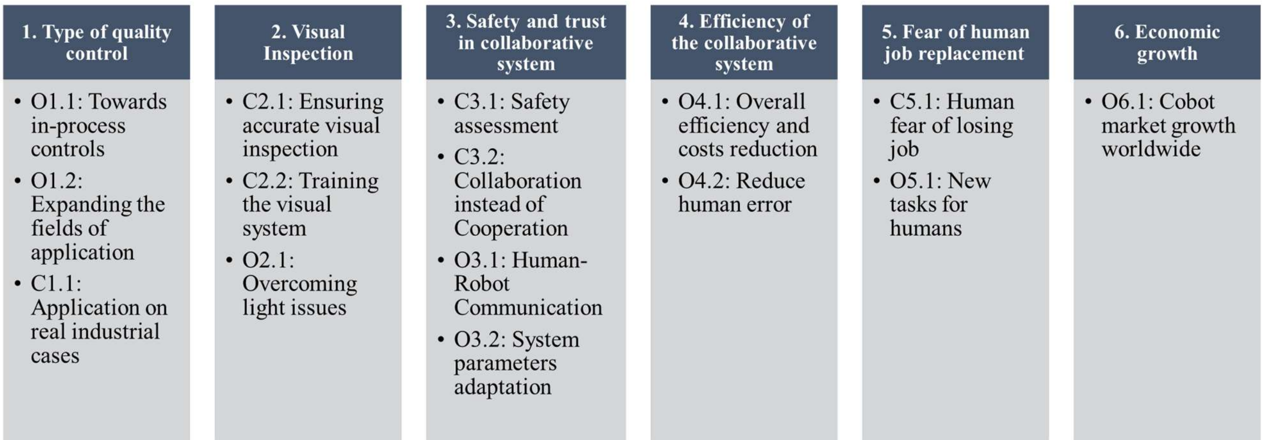

Figure 6 – Schematic of analysis dimensions with related challenges (C) and opportunities (O) of HRC in quality control.

From the results of the analysis, it is clear that collaborative robotics in quality still plays a marginal role compared to the many industrial applications currently available. In order for this new paradigm of quality control to become widely used, the challenges listed in Fig. 6 must be faced and overcome, trying to take full advantage of the opportunities and benefits it can offer.

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REFERENCES

Andersson, S.K.L., Granlund, A., Hedelind, M. and Bruch, J. (2020), "Exploring the Capabilities of Industrial Collaborative Robot Applications", available at:https://doi.org/10.3233/ATDE200148 (accessed April 6th, 2022).

Antony, J., McDermott, O. and Sony, M. (2021), "Quality 4.0 conceptualisation and theoretical understanding: a global exploratory qualitative study", *The TQM Journal*, ahead of print, available at:https://doi.org/10.1108/TQM-08-2021-0242.

Brito, T., Queiroz, J., Piardi, L., Fernandes, L.A., Lima, J. and Leitão, P. (2020), "A machine learning approach for collaborative robot smart manufacturing inspection for quality control systems", *30th International Conference on Flexible Automation and Intelligent Manufacturing (FAIM2021)*, Vol. 51, Procedia Manufacturing, 15-18 June 2021, Athens, Greece, pp. 11–18.

Bruker Alicona. (2019), *Non-Contact and Highly Accurate Measurement of Critical Turbine Engine Components*.

Dias, A.M., Carvalho, A.M. and Sampaio, P. (2021), "Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality", *International Journal of Quality & Reliability Management*, ahead of print, available at:https://doi.org/10.1108/IJQRM-07-2021-0247/FULL/XML.

Doltsinis, S., Krestenitis, M. and Doulgeri, Z. (2020), "A machine learning framework for real-time identification of successful snap-fit assemblies", *IEEE Transactions on Automation Science and Engineering*, IEEE, Vol. 17 No. 1, pp. 513–523.

European Commission. (2020), "Industry 5.0", available at: https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en (accessed April 6th, 2022).

Genta, G., Galetto, M. and Franceschini, F. (2020), "Inspection procedures in manufacturing processes: recent studies and research perspectives", *International Journal of Production Research*, Taylor & Francis, Vol. 58 No. 15, pp. 4767–4788.

Hentout, A., Aouache, M., Maoudj, A. and Akli, I. (2019), "Human–robot interaction in industrial collaborative robotics: a literature review of the decade 2008–2017", *Advanced Robotics*, Taylor & Francis, Vol. 33 No. 15–16, pp. 764–799.

Jian, B.-L., Tsai, C.-S., Kuo, Y.-C. and Guo, Y.-S. (2021), "An image vision and automatic calibration system for universal robots", *Journal of Low Frequency Noise, Vibration and Active Control*, Vol. 40 No. 1, pp. 347–366.

Karami, H., Darvish, K. and Mastrogiovanni, F. (2020), "A task allocation approach for human-robot collaboration in product defects inspection scenarios", *2020 29th IEEE International Conference on Robot and Human Interactive Communication (RO-MAN)*, IEEE, August 31 - September 4, 2020 - Virtual Conference, pp. 1127–1134.

Knudsen, M. and Kaivo-Oja, J. (2020), "Collaborative Robots: Frontiers of Current Literature", *Journal of Intelligent Systems: Theory and Applications*, No. June, pp. 13–20.

Kopp, T., Baumgartner, M. and Kinkel, S. (2020), "Success factors for introducing industrial human-robot interaction in practice: an empirically driven framework", *International Journal of Advanced Manufacturing Technology*, Springer Science and Business Media Deutschland GmbH, Vol. 112 No. 3, pp. 685–704.

Küpper, D., Knizek, C., Ryeson, D. and Noecker, J. (2019), "Quality 4.0 takes more than technology", *Boston Consulting Group (BCG)*, pp. 1–14, available at https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology (accessed May 4th, 2022).

Lasi, H., Fettke, P., Kemper, H.-G., Feld, T. and Hoffmann, M. (2014), "Industry 4.0", *Business & Information Systems Engineering*, Springer, Vol. 6 No. 4, pp. 239–242.

Lopez-Hawa, H., VanPelt, A., Emmanuel, S. and Yihun, Y. (2019), "Automated Scanning Techniques Using UR5", *Journal of Robotics*, Vol. 2019 No. ID 5304267, p. 8.

Maddikunta, P.K.R., Pham, Q.-V., Prabadevi, B., Deepa, N., Dev, K., Gadekallu, T.R., Ruby, R., *et al.* (2021), "Industry 5.0: A survey on enabling technologies and potential applications", *Journal of Industrial Information Integration*, Elsevier, p. 100257.

El Makrini, I., Merckaert, K., Lefeber, D. and Vanderborght, B. (2017), "Design of a collaborative architecture for human-robot assembly tasks", *IROS 2017 - IEEE/RSJ International Conference on Intelligent Robots and Systems*, IEEE, 24-28 September 2017, Vancouver, British Columbia, Canada, pp. 1624–1629.

Montgomery, D.C. (2012), *Statistical Quality Control*, 7th Ed., John Wiley & Sons, New York.

Müller, R., Vette, M. and Scholer, M. (2014), "Inspector robot - A new collaborative testing system designed for the automotive final assembly line", *Assembly Automation*, Vol. 34 No. 4, pp. 370–378.

Papanastasiou, S., Kousi, N., Karagiannis, P., Gkournelos, C., Papavasileiou, A., Dimoulas, K., Baris, K., *et al.* (2019), "Towards seamless human robot collaboration: integrating multimodal interaction", *International Journal of Advanced Manufacturing Technology*, Vol. 105 No. 9, pp. 3881–3897.

Pichler, A., Akkaladevi, S.C., Ikeda, M., Hofmann, M., Plasch, M., Wögerer, C. and Fritz, G. (2017), "Towards shared autonomy for robotic tasks in manufacturing", *27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017*, Vol. 11, Procedia

Manufacturing, 27-30 June 2017, Modena, Italy, pp. 72–82.

Romero, D., Bernus, P., Noran, O., Stahre, J. and Fast-Berglund, Å. (2016), “The operator 4.0: Human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems”, *IFIP International Conference on Advances in Production Management Systems*, Springer, pp. 677–686.

Rooker, M., Hofmann, M., Minichberger, J., Ikeda, M., Ebenhofer, G. and Pichler, A. (2014), “Quality Inspection performed by a Flexible Robot System”, *Proceedings of the Austrian Robotics Workshop 2014*, 22-23 May, Linz, Austria, pp. 47–51.

Sony, M., Antony, J. and Douglas, J.A. (2020), “Essential ingredients for the implementation of Quality 4.0: a narrative review of literature and future directions for research”, *The TQM Journal*, Vol. 32 No. 4, pp. 779–793.

Statista. (2022), “Collaborative robots worldwide”, available at: https://www.statista.com/topics/8062/collaborative-robots-worldwide/ (accessed April 6th, 2022).

Syberfeldt, A. and Ekblom, T. (2019), “Improved automatic quality inspections through the integration of state-of-the-art machine vision and collaborative robots”, in Yan, J. and Price, M. (Eds.), *Advances in Manufacturing Technology XXXIII: Proceedings of the 17th International Conference on Manufacturing Research*, IOS Press Advances in Transdisciplinary Engineering, 10–12 September, Belfast, UK, pp. 107–112.

Universal Robots. (2022), “Universal Robots: case stories”, available at: https://www.universal-robots.com/case-stories/quality-inspection/ (accessed April 6th, 2022).

Wang, L., Gao, R., Váncza, J., Krüger, J., Wang, X. V., Makris, S. and Chryssolouris, G. (2019), “Symbiotic human-robot collaborative assembly”, *CIRP Annals*, CIRP, Vol. 68 No. 2, pp. 701–726.

El Zaatari, S., Marei, M., Li, W. and Usman, Z. (2019), “Cobot programming for collaborative industrial tasks: An overview”, *Robotics and Autonomous Systems*, Elsevier B.V., Vol. 116, pp. 162–180.

World State of Quality: a frontier approach to benchmark the performance of countries worldwide

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STRUCTURED ABSTRACT

Purpose - The World State of Quality (WSQ) Project aims to evaluate, analyse, rank and categorise countries according to their performance in quality as a multidimensional concept. The Project involves the computation of an overall score for each country, obtained as a weighted average of ranking positions of 16 metrics, with weights determined by a panel of experts.

Methodology- This work proposes an alternative strategy for that procedure, using a Benefit-of-the-Doubt (BoD) Composite Indicator approach under the framework of Data Envelopment Analysis (DEA). This strategy avoids the need of using subjective weights and normalising data by rank positions, using a more objective procedure to obtain the countries' ranking. A new overall score of the World State of Quality is proposed, which allows the categorisation of countries' performance. The novel insights resulting from the use of this methodology are discussed, including the identification of strengths and weaknesses of the various countries, and the peers that can be used for facilitating continuous improvements policies.

Findings - The results show that the BoD approach and the original method used by the WSQ Project present comparable results. Countries' strengths and weaknesses and their suitable peers and targets for benchmarking are presented with illustrative examples.

Originality/value – A novel frontier approach for countries' benchmarking regarding their performance in quality is proposed, incorporating new insights into the current method.

Keywords: macroquality, composite indicator, benchmarking, Benefit-of-the-Doubt.

Paper type: Research paper

1 INTRODUCTION

The comparison of companies or business units regarding their performance in quality is a well-established procedure, often employed to identify best practices and foster continuous improvement. However, assessing quality performance at a country level is a challenging task, requiring a broader approach to deal with different contexts, cultures and societal environments. This macroquality concept was discussed by Saraiva et al. (2020) and used as a foundation to develop the World State of Quality (WSQ) Project, aiming to evaluate countries regarding their quality performance. In this context, a comparative analysis of countries can support the identification of priorities for improvement and development of the best policies to enhance national quality levels. The macroquality assessment includes enablers and activities specific to several quality dimensions and considers outcomes related to the achievement of a sustainable and cohesive environment.

The WSQ Project was developed by a research team from Portugal (Cubo et al., 2019; Sampaio et al., 2018; Saraiva et al., 2020), and the initial findings were published using data collected in 2016 from a set of public databases regarding the performance of European countries. Since 2017, the team extended the analysis to countries outside Europe, such that the Project could achieve a worldwide scope. In this context, the Overall World State of Quality Ranking Score (OWQS) is computed for each country based on 16 indicators, considering ten different dimensions. This overall score is obtained from a weighted average of the indicators' rank positions, where the weights are defined by a group of quality experts. Based on the final ranking according to OWQS values, the countries are classified into four categories.

In this work, an alternative strategy to the estimation of the OWSQ, the construction of a Composite Indicator (CIs) based on the "Benefit-of-the-Doubt" (BoD) modelling approach is proposed. The BoD models are built under the Data Envelopment Analysis (DEA) framework and have been broadly adopted as benchmarking tools (Nardo et al., 2008). This approach can bring new insights compared to the current method for a variety of reasons. First of all, BoD models do not require the prior assignment of aggregation weights, as the weights are endogenous to the existing data and estimated using optimisation techniques. These models can deal with data in their original form, so they do not need to be transformed using rank positions. Furthermore, the models enable the identification of the strengths and weaknesses of the decision-making units (DMUs), as well as the selection of the most suitable peers and targets for benchmarking purposes. Those novel insights represent the literature gap that this work intends to fill. The objectives of this work are as follows: (i) to rank countries based on their macroquality performance using a new method, (ii) to propose a new classification of countries into four WSQ categories, (iii) to identify countries' strengths and weaknesses, and (iv) to determine appropriate targets and benchmarking peers.

This paper unfolds as follows. A brief literature review, covering country evaluations regarding quality performance and the construction of CIs using a BoD approach is presented in Section 2. Section 3 introduces the dataset utilised for the analysis. The proposed methodology is described in Section 4. The results are discussed in section 5, and section 6 presents the conclusions.

2 LITERATURE REVIEW

The literature review detailed in the following subsections covers different types of studies comparing countries regarding their performance in quality. The use of BoD models to produce composite indicators (CIs) for benchmarking is also discussed.

2.1 Quality performance assessment of countries

Comparative studies of country performance using CIs are frequently used to identify strengths and weaknesses and estimate the potential for improvement. Some of the topics that received special attention in the literature include competitiveness (Aiginger, 1998), innovation (Dutta et al., 2020), ease of doing business (Qazi et al., 2021; Rogge and Archer, 2021), inequality (Farris, 2010) and happiness (Helliwell et al., 2020).

Assessments and comparative studies of quality practices are usually performed at an organisational level. They are often based on quality system models, such as the renowned ISO 9000 set of standards (Ahmed et al., 2005; Ismail et al. 1998; Chen et al., 2019). A few studies are also based on the implementation of diverse quality management frameworks, such as Six Sigma (Van Iwaarden et al., 2008), or criteria outlined in quality award models, as the European Foundation for Quality Management (EFQM) Excellence Model (Bou-Llusar et al., 2009) and the Malcolm Baldridge National Quality Award (Jaeger et al., 2013; Lau et al., 2004).

Comparative studies have also been performed involving firms in different countries, such as Turkey and United Kingdom (Clegg et al., 2013), Argentina and Uruguay (Bello-Pintado and Merino-Díaz-de-Cerio, 2013) or comparing Eastern and Western nations (Dahlgaard et al. 1998). Two global studies comparing more than a thousand companies worldwide covering themes such as customer impact, industry standards' trends, training methods and governance structures were published by the American Society of Quality (APQC and ASQ 2013, 2016). Those researches also highlight similarities and contrasts between countries and regions, but all of them focus on the comparison of firms in different nations as a way to assess the diverse scenarios of quality practice implementation. Nevertheless, studies comparing countries' performance in quality at a macro level are scarce.

Determining quality or excellence at the regional or national level, rather than at the level of a single business, is a difficult task. According to Saraiva et al. (2020), defining quality on a larger scale requires a multidimensional approach called “macroquality”. This notion encompasses not only quality related actions and facilitators but also the factors that lead to the enhancement of an environment supportive to quality improvement.

The World State of Quality (WSQ) Project was developed to fill this gap. The Project was conceived to evaluate the macroquality of countries, identifying priorities and areas for improvement. As a result, a national agenda for quality and excellence can be established. The first study in the WSQ project was issued in 2016, covering 28 nations in the European Union (Sampaio et al., 2018; Saraiva et al., 2020) and considering ten different dimensions and 21 indicators. In the following year, the Project was expanded to include nations worldwide. The number of indicators was then reduced to 16, and some of them had to be modified, as required to be adapted to the new global context (Cubo et al., 2019).

The methodology employed by the WSQ Project involves the computation of the Overall World State of Quality (OWSQ) score as a weighted average of the countries’ rank positions. The values of the various indicators are not directly used, as they are converted to a normalised scale of ordered ranks. The weights are provided by a panel of international quality specialists. The OWSQ score can be used to compare the different countries and a final rank is generated with the countries with the lowest score representing the top performers. Finally, the countries are grouped by categories according to their rank order. The limits of the categories are set at positions with larger differences between consecutive ranked countries. The five categories created in 2017 were Leader, Follower, Moderate, Lagging, and Beginner, but they were reduced to four in 2018 with the elimination of the category Lagging.

2.2 The use of the Benefit-of-the-Doubt models for constructing composite indicators

A combined analysis of a set of performance indicators is necessary to conduct a multiple-dimensional performance analysis of a set of units for benchmarking purposes. Individual indicators can be aggregated into a single index to create a CI. The Handbook on Constructing Composite Indicators (Nardo et al., 2008) published by the Organisation for Economic Co-operation and Development (OECD) discusses that CIs may accommodate multi-dimensional and complex realities and are often easier to interpret than large sets of individual indicators. However, if improperly developed or misunderstood, they could convey inaccurate signals. Moreover, the selection of indicators and weights could be a source of disagreement, and the aggregation of the various metrics into an overall measure of performance may be challenging, involving creativity and expertise.

Among a large variety of methodological approaches that may be employed for constructing CIs, the Data Envelopment Analysis (DEA) technique has become increasingly popular. DEA is a linear programming technique proposed by Charnes et al. (1978) for evaluating the performance of a group of entities, called “Decision Making Units” (DMUs), that employ multiple inputs to produce multiple outputs. The “Benefit-of-the-Doubt” (BoD) approach was developed by Cherchye et al. (2007) as an application of DEA for building CIs. The BoD technique can overcome the concerns about the need for normalisation and identification of “right” weights, allowing an easy and intuitive interpretation of results. The use of this method based on DEA has the advantage of being data-driven, avoiding an extensive interaction with stakeholders to decide the relative importance of indicators. Furthermore, no normalisation or conversion of units of measurement is necessary for BoD, as the data are used in their original scale. The BoD models have evolved considerably, being adapted to solve different kinds of problems. Various strategies have been applied, for example, to deal with undesirable metrics or to restrict weights within certain bounds.

Weight restrictions may be necessary to prevent the model from using many weight values equal to zero, which may occur in case of a totally free choice of weights. A wide range of weight restriction approaches have been proposed in the DEA literature (Allen et al., 1997; Khalili et al., 2010). The most common type of those restrictions in DEA applications, known as assurance regions type I (ARI), impose limits to ratios between input weights or between output weights.

Once the BoD model is defined as a linear programming problem, it can be solved for each DMU. The optimum solution for the DMU under assessment yields the most favourable weights for that DMU, allowing the estimation of a CI score, ranging from zero to one. After the linear program is computed for all the DMUs, the resulting CI scores enable the ranking of DMUs performance. The best performing DMUs are assigned a CI score equal to one. The hyperplane formed by connecting the efficient DMUs that involves all the data is known as the efficient frontier.

Countries have been used as units of assessment by BoD models in a wide range of applications, such as human development (Rogge, 2018; Van Puyenbroeck and Rogge, 2020), competitiveness (Bowen and Moesen, 2011), social inclusion (Verbunt and Rogge, 2018), environmental performance (Zanella et al, 2013), transportation (Gruetzmacher et al., 2021) and active ageing of population (Amado et al., 2016).

3 DATASET PRESENTATION

The conceptual model of the WSQ Project aims to reflect the quality performance of a country at a broad level including ten dimensions. These dimensions are different in nature, either reflecting the quality-practice approaches of the different countries, or reflecting more intangible concepts, such as “the achievement of sustainable, cohesive and competitive happiness for all that do live or relate with that country” (Saraiva et al., 2020). From each dimension, one or two indicators were chosen from well-known and reliable sources, updated on a regular basis. Some indicators are given in a per capita form to take into account for the country's size. **Erro! A origem da referência não foi encontrada.** displays WSQ dimensions and their respective indicators, with their sources and units of measure (Saraiva et al., 2018).

Table 1 – WSQ Project dimensions and indicators.

DIMENSION	CODE	INDICATOR	UNIT	DATA SOURCE
Organisation	I01	Number of ISO 9001 Certified Organisations	Per 1,000 inhabitants	ISO[1] Survey
Professionals	I02	Number of IAQ Members	Per 1,000 inhabitants	IAQ[2]
Research	I03	Number of Indexed Quality Papers Published	Per 1,000 inhabitants	Scopus, ISI[3]
	I04	Number of Universities in International Research Rankings	Per 1,000 inhabitants	Shangai Ranking
Education	I05	Education Index	score	HDR[4]
Health	I06	Healthy Life Expectancy	age	WHO[5]
	I07	Birth Mortality Rate	Per 1,000 live births	World Bank
Competitiveness	I08	Global Competitiveness Index	score	WEF[6]
	I09	Gross Domestic Product per capita	US dollars	World Bank
Social Cohesion	I10	Gini Index	percentage	World Bank
Sustainability	I11	Number of ISO 14001 Certified Organisations	Per 1,000 inhabitants	ISO
	I12	Ecological Footprint	gha per capita	Footprint Network
Innovation	I13	Global Innovation Index	score	GII[7] Project - WIPO[8]
	I14	Ease of Doing Business Score	score	World Bank
Satisfaction	I15	World Happiness Index	score	SDSN[9]
	I16	Employee Engagement Index	percentage	Gallup

Notes: [1]ISO: International organisation for Standardization; [2]IAQ: International Academy for Quality; [3]ISI: Web of Knowledge, [4]HDR: Human Development Report; [5]WHO: World Health Organisation; [6]WEF: World Economic Forum; [7]GII: Global Inovation Index; [8]WIPO: World Intellectual Property Organisation; [9]SDSN: Sustainable Development Solutions Network.

For the dimension Organisation, the chosen indicator is the number of organisations certified by ISO 9000 (I01), the international set of standards for certification in quality management systems.

The number of members of the International Academy for Quality (IAQ) in each country (I02) is the indicator selected for the dimension Professionals. IAQ is a worldwide non-governmental organisation for professionals dedicated to the development and promotion of quality related methodologies and applications.

In the dimension Research, two metrics were defined. The first one is the number of indexed quality papers published by the country (I03). The sources of that metric are the relevant research databases of ISI (Web of Science) and Scopus, and the number of papers is searched using specific terms in the paper title, abstract and keywords. The second indicator in the dimension Research is the number of the country's universities in the top 500 high-level education institutions listed by the Shanghai ranking (I04).

For the dimension Education, the Education Index (I05), issued annually by the United Nations Development Program was chosen. The Education Index is part of the Human Development Index and represents the average between the expected and the actual number of years of schooling from a country.

Two metrics were selected for the dimension Health: The Health Life Expectancy (I06) and the Birth Mortality Rate (I07). The Healthy Life Expectancy is computed by World Health Organisation and represents the number of years that a person is expected to live in good health conditions aggregated to the country level. The Birth Mortality Rate, issued by the World Bank, is the number of deaths of children before completing one year of life divided per 1,000 live births.

The Global Competitiveness Index (I08) and the Gross Domestic Product per capita (I09) compose the dimension Competitiveness. The Global Competitiveness Index is published by the World Economic Forum and is a CI, including several metrics related to different aspects of competitiveness. The Gross Domestic Product, reported by the World Bank, represents the entire market value of all products and services generated by the economy of a country in a given year.

The dimension Social Cohesion includes the Gini Index (I10), which estimates the deviation from a perfectly equal income within a country. Lower values for this measure indicate a better distribution of income.

In the dimension of Sustainability, two metrics are included: the number of ISO 14001 certified organisations (I11) and the Ecological Footprint (I12). ISO 14001 is the international standard for certification of organisations' environmental management systems and reflects the commitment of organisations to the environmental management of their businesses. The Ecological Footprint expresses the amount of natural resources consumed by the country's population measured in the global hectares (gha) per person, a standardised metric of natural resource consumption. It is computed by the research organisation Global Footprint Network.

The dimension Innovation presents the Global Innovation Index (I13) and the Ease of Doing Business Score (I14). The Global Innovation Index is issued by the World Intellectual Property Organisation (WIPO), a self-funding agency of the United Nations. It is a CI that uses around 80 different indexes, covering several aspects of innovation inputs and outputs. The Ease of Doing Business Score is calculated by the World Bank, and it is also a CI of 41 metrics. The metrics represent regulatory best practices in an economy's country.

Finally, the dimension Satisfaction presents two indicators. The first one is the World Happiness Index (I15), which is annually issued by the Sustainable Development Solutions Network, created by the United Nations to support the implementation of the Sustainable Development Goals. This indicator used data collected by the company Gallup in its World Poll Surveys. The second indicator in the dimension of Satisfaction is the Employee Engagement Index (I16), reported by Gallup, which assesses whether employees are more or less motivated about their jobs depending on how effectively their basic needs are addressed at work.

This work analyses the data published in the World State of Quality report for 2018, which includes 118 countries worldwide, and considers the most recent data available by the mid of the year for each indicator (Saraiva et al., 2018).

The indicators Birth Mortality Index (I07), Gini Index (I10) and Ecological Footprint (I12) present desirable outcomes for lower score values, so they cannot be directly compared to the other measures. They can be converted to positive outcomes, through the replacement of all the data by a large number minus their original values. According to Zanella et al. (2015), the large number should not be exactly the maximum value of the output to ensure the feasibility of the model when weight restrictions are present. Therefore, we used the maximum output of each indicator added to 0.1 for that purpose.

As DEA is sensitive to outliers, it was established that the indicators would range from a minimum value of its average minus three times its standard deviation and a maximum value of its average plus three times its standard deviation. Values beyond this interval were replaced by the range limits. This procedure is recommended by Zanella et al. (2013) to mitigate the impact of extreme values that can bias the performance evaluation. Twelve values were changed in this step, representing 0.6% of the dataset. Those were the only transformations applied to the raw data. The resulting descriptive statistics for the dataset are presented in Table 2.

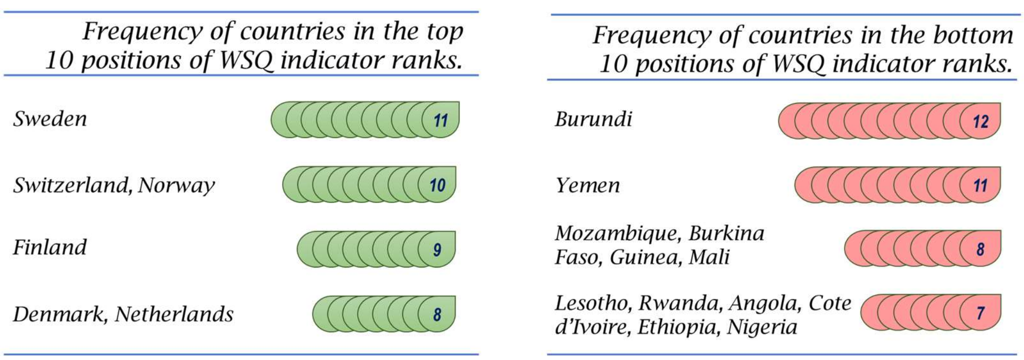
In Table 2, most indicators present high coefficient of variation, reflecting the wide range of performance among the analysed countries.

A further in-depth examination of the dataset indicates a considerable disparity in national performance based on geography. Figure 1 depicts the most often occurring nations at the top and bottom of the 16 indicators' rankings. The highest performing countries are predominantly European (Figure 1a), mainly Scandinavian. Less developed countries, primarily from Africa, are among the lowest performers (Figure 1b).

Table 2 – Descriptive Statistics for all countries in 2018.

CODE	INDICATOR	MEAN	STANDARD DEVIATION	COEFFICIENT OF VARIATION	MINIMUM	MAXIMUM
I01	Number of ISO 9001 Certified Organisations per 1,000 inhabitants	0.24	0.35	1.50	0.00	1.75
I02	Number of members of International Academy for Quality per 1,000 inhabitants	2.99×10^{-5}	7.85×10^{-5}	2.63	0.00	3.80×10^{-4}
I03	Number of Indexed Quality Papers Published per 1,000 inhabitants	0.04	0.06	1.48	0.00	0.22
I04	Number of Universities in International Research Rankings per 1,000 inhabitants	1.18×10^{-4}	2.45×10^{-4}	2.08	0.00	9.00×10^{-4}
I05	Education Index (score)	0.69	0.17	0.24	0.29	0.94
I06	Healthy Life Expectancy (age)	64.70	6.63	0.10	46.60	74.80
I08	Global Competitiveness Index (score)	4.28	0.67	0.16	2.87	5.86
I09	Gross Domestic Product per capita (US dollars)	14192.00	18291.00	1.29	320.00	73272.00
I11	Number of ISO 14001 Certified Organisations per 1,000 inhabitants	0.08	0.12	1.55	0.00	0.57
I13	Global Innovation Index (score)	35.90	12.20	0.34	15.00	68.40
I14	Ease of Doing Business Results (distance to frontier)	65.70	11.50	0.18	31.20	84.10
I15	World Happiness Index (score)	5.46	1.09	0.20	2.90	7.63
I16	Employee Engagement Index (%)	19.00	8.72	0.46	3.30	39.40
I07	Birth Mortality Rate[*1] (per 1,000 live births) – (Complement to 72.5)	53.40	18.20	0.34	0.10	70.70
I10	Gini Index[*1] (%)– (Complement to 64.8)	27.00	8.54	0.32	1.24	48.20
I12	Ecological Footprint[*1] (gha pc) – (Complement to 12.38)	9.22	2.01	0.22	2.90	11.80

[*1] – Undesirable output



(a) Best performers in individual WSQ indicators (b) Worst performers in individual WSQ indicators

Figure 1- Most frequent countries at the top 10 and bottom 10 WSQ individual indicators ranking – 2018.

4 METHODOLOGY

The proposed methodology presents three stages. The first one, in subsection 4.1, details the BoD Model used to estimate the performance of the countries under assessment. This procedure is used as an alternative to the current approach employed in the WSQ Project. The following subsections displays other by-products of the BoD approach. The identification of nations' strengths and shortcomings is described in the subsection 4.2. Finally, the most suitable peers for benchmarking and targets for each indicator are explored in in subsection 4.3.

4.1 BoD model for benchmarking countries

The linear programming model displayed in (1) is known as an output-oriented BoD model and will be employed in this work to construct CIs (Van Puyenbroecket et al., 2021; Zanella et al., 2013; Zanella et al., 2015). In this model, y_{rj} represents the observed value of indicator r for DMU j ($r = 1, \dots, s$ and $j = 1, \dots, n$) and u_r is the weight assigned to indicator r. Note that the set of weights u_r is not known a priori and needs to be determined by optimisation. The letter o denotes the DMU that is being evaluated, and the variable v represents the ratio between the performance of the efficient DMUs and the performance of the DMU under assessment (o). As we are looking for the most favourable weights for o, the objective of the optimisation problem is to minimise v.

$$
\begin{aligned}
& minimise\ v \\
& subject\ to \sum_{r=1}^{s} u_r y_{ro} = 1 \qquad\qquad (1) \\
& \sum_{r=1}^{s} u_r\, y_{rj} - v \le 0, \quad j = 1, \dots, n \\
& v \ \ge 0 \\
& u_r \ge 0, \qquad\qquad r = 1, \dots, s
\end{aligned}
$$

The optimum solution of the problem (1) yields the weights for DMU o. The value v obtained for the objective function gives the degree to which the benchmark DMUs outperforms DMU o, being greater or equal to one. The value of the composite indicator (CI), that summarises the performance of DMU o, is given by $1/v$ and ranges from zero to one. If the score CI is equal to one, DMU o is itself a benchmark.

Now that we could generate a CI for DMU o, it is worth noting that the same process must be repeated for all the DMUs. Therefore, the linear programming problem must be solved n times for all the DMUs under consideration. At the end of this process, all DMUs are assigned a CI score, all ranging from zero to one, so they can be compared to each other. In each case, a set of most-favourable weights will also be produced, indicating the trade-offs between the various indicators for the country being evaluated.

In linear programming theory, every linear programming problem has an alternative problem derived from it, which provides equivalent solutions, but uses different decision variables. Primal refers to the initial linear programming problem, whereas the derived linear programming problem is known as dual. The dual formulation of model (1) is presented as model (2). The primal formulation in BoD is often referred as weights' formulation and the dual is known as envelopment formulation. The envelopment formulation in BoD models is often used to identify peers and targets of the DMUs under consideration for benchmarking purposes (Zanella et al., 2013; Pereira et al., 2021; Henriques et al., 2020; Oliveira et al., 2020).

In model (2), the decision variables λ_j mean the degree of similarity between the DMU under consideration and its peers. The factor θ by which all outputs of the DMU under evaluation can be proportionally raised to meet the target values corresponds to the objective function of model (2). The value of CI can be also obtained from model (2) as $1/\theta$, and it is equivalent to the CI given by model (1).

$$
\begin{aligned}
& maximise\ \theta \\
& subject\ to\ \ \theta y_{ro} - \sum_{j=1}^{n} \lambda_j y_{rj} \leq 0, \qquad r = 1, \dots, s \\
& \sum_{j=1}^{n} \lambda_j \leq 1, \\
& \lambda_j \geq 0, \qquad j = 1, \dots, n \\
& \theta \ \ is\ free
\end{aligned} \tag{2}
$$

In the model displayed in (1), the weights can be chosen freely during the optimisation process. That could lead to the generation of weights equal to zero for some of the indicators, and, therefore, the importance of some dimensions can be neglected. To overcome this limitation, constraints must be added to the model to limit the range of the weights produced for each indicator or for each dimension being assessed.

In this work, two alternatives for weight restrictions are applied. In both alternatives, an "artificial" country is considered in the proposed strategy, presenting the average performance among all countries. Therefore, the indicators' values of this country are equivalent to the average of all countries' indicators ($\overline{y}_r$). In the first option presented in (3), we impose that the weights of the "artificial" country match the original weights provided by the WSQ Project (w_r), presented in Table

3. This option is used to illustrate the difference between the BoD approach and the weighted average method using rank positions employed in the WSQ Project.

$$\frac{u_r \overline{y}_r}{\sum_{r=1}^{s} u_r \, \overline{y}_r} = w_r, \qquad r = 1 \dots s \qquad (3)$$

Table 3 - Fixed weights used in the WSQ Project.

Indicator	I01	I02	I03	I04	I05	I06	I07	I08	I09	I10	I11	I12	I13	I14	I15	I16
Weight (w_r) (%)	6.00	4.80	6.24	5.94	5.93	6.40	6.24	6.63	6.41	5.67	6.09	6.20	6.61	6.59	7.69	6.54

A more flexible approach using ARI restrictions is proposed in (4), using a lower bound ϕ_r for all the indicators. Establishing a lower threshold ϕ_r can avoid the generation of zero weights and gives more freedom for the model to determine optimum solutions.

$$\frac{u_r \overline{y}_r}{\sum_{r=1}^{s} u_r \, \overline{y}_r} \geq \phi_r, \qquad r = 1 \dots s \qquad (4)$$

The alternative approaches for weight restrictions using (3) or (4) can be added to model (1) to generate different perspectives for countries performance assessment.

4.2 Identification of strengths and weaknesses

Using the weights assigned by the BoD model, it is possible to analyse which indicators are given higher importance in the performance of the countries under assessment. The CI score can be split into indicator contributions representing virtual weights. The virtual weights are obtained as the product of each indicator's value (y_{ro}) by its weight (u_r) given by the model results, and the virtual weights of a given country sum up to one as shown in the first restriction of model (1).

For the identification of strengths and weaknesses, the outcomes generated from the BoD model with constraints (4) are employed. Since the lower bound for the weights is ϕ_r on average, we assume that the model provides virtual weights higher than ϕ_r aiming to favour the country under assessment for the indicators with best performance. Those represent the country's strengths, while the indicators with low virtual weights represent the country's weaknesses. In the case of the OWSQ original method, considering that the score is calculated by multiplying the fixed weights by the indicator's ranking position, the final score represents a weighted average of the country's ranking positions for each indicator. Therefore, in this situation, it is not possible to compute the contribution of each indicator to the country's overall score.

4.3 Identification of peers and targets

The BoD models can be used to identify the country's peers for benchmarking purposes. The peers are other countries whose results a country should consider to enhance its performance. In order to look for more comparable peers and achievable targets, we choose to run the BoD models for country clusters and identify efficient frontiers within homogeneous groups. The clusters were made up of countries with comparable geographical locations. The use of geography as an exogenous variable here is justified by the large variations in countries' performances associated with this factor, as previously discussed.

The λ_j values obtained from the BoD model (2) within each cluster indicate the measure of similarity between a country and its peers. The values of λ_j that are different from zero identify the country's peers. The targets for each indicator are taken from the indicator values of the peers, that outperforms the country under assessment.

5 RESULTS AND DISCUSSION

This section is divided in three parts. Subsection 5.1 presents the results of countries' ranks and the proposed categorisation, discussing the differences between OWSQ and BoD approaches. Subsection 5.2 discusses nations' strengths and weaknesses that can be extracted from the BoD model, with illustrative examples of two countries. The same two countries are used as examples to discuss the identification of peers and targets in Subsection 5.3.

5.1 The overall ranking of countries

Overall CIs are generated for all the countries, using the two different approaches for weight restrictions in the BoD model. The first one imposes that an "average" DMU uses the same weights employed to generate the original Overall World State of Quality (OWSQ) score. The second one is more flexible and forces the "average" DMU to present weights that are higher or equal to ϕ_r for each indicator, according to expression (4). The value of ϕ_r was chosen as 4% (0.04) for all the indicators in this work. This value was selected, because it allows that all 16 indicators present significant contributions of at least 64% and still there is some flexibility (36%) for searching for the most favourable weights in each country.

The CIs and rank positions computed from the BoD models and a comparison with the Overall World State of Quality results (OWSQ) are shown in Table A.1 in Appendix A. In this table, the countries are also presented with their three-digit codes, according to the international standard ISO 3166. We categorise the nations by dividing the BoD flexible-weight rank into quartiles, with 29 elements in the first quartile, 30 in the second, 29 in the third and 30 countries in the fourth quartile. As a result, the first quartile, covering the top 25% higher positions in the rank, represents the category Leader. Countries in the following quartiles are designated as Followers, Moderates, and Beginners, in this order. The use of quartiles to categorize the countries seems to be a more viable approach in this case, because the larger differences between subsequent nations in the BoD CI ranking, which is the original WSQ categorization criteria, are concentrated within the top 10 rank positions.

A comparison between the OWSQ rank and BoD ranks is performed using Spearman's rank correlation technique. When the OWSQ rank and BoD rank using the same weights are compared, the Spearman's rho coefficient is 0.984, showing a strong correlation between the two ranks. The resulting p-value is less than 0.001 indicating that the correlation is statistically significant. The results of applying OWSQ weights in the BoD model show that both ranks are comparable, although no normalisation procedure was used. In this context, information loss is minimised by utilising actual data rather than ranking positions. A similar analysis between the OWSQ rank and BoD flexible-weight approach yields a Spearman's rho coefficient of 0.840 and a p-value of less than 0.001. The correlation is still high and statistically significant in this scenario, even though the weights are allowed to vary aiming to highlight countries' best outcomes.

The BoD model with ARI weight restrictions at a minimum of 4% is used for the following analyses. A scatter plot showing the correlation between the OWSQ rank and the BoD rank positions is presented in Figure 2. The shaded area around the trend line shows the 95% confidence interval for the correlation. The categories assigned to the OWSQ classification are colour-coded in the graph and the categories according to the BoD ranking positions are shown in the graph area limited by the dotted horizontal lines.

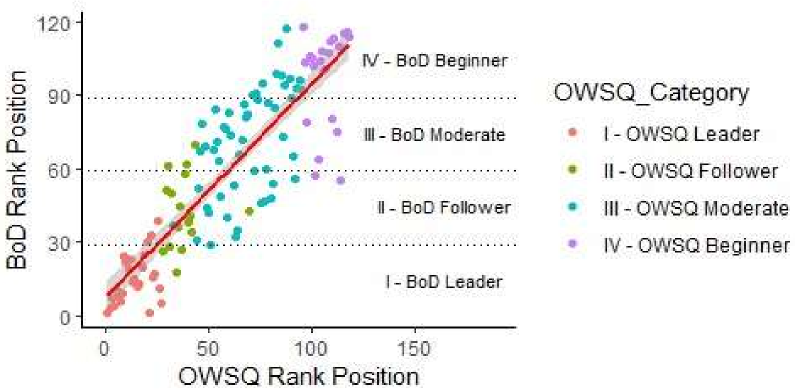
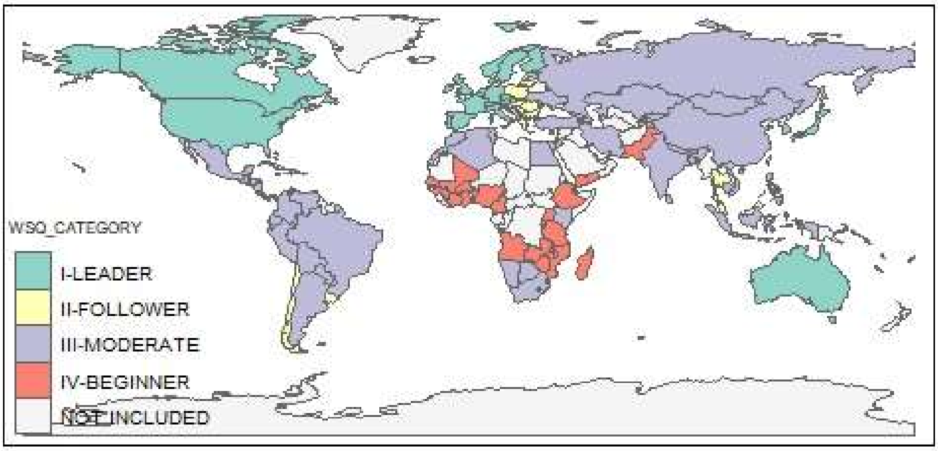
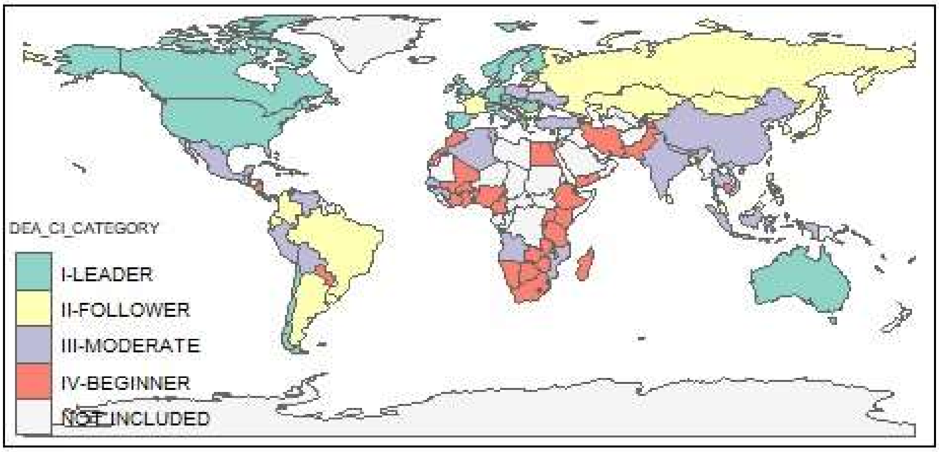


Figure 2 - Scatter plot of BoD and OWSQ rank positions.

In Figure 2, some variation between the original OWSQ classification and the BoD categories can be noticed. The similarities and differences between both classification methods can be better illustrated in the world maps in Figure 3.



(a) OWSQ classification - 2018



(b) BoD Classification - 2018

Figure 3 - Classification of countries using two different approaches.

The OWSQ categories are unbalanced in terms of the number of elements, with the category Moderate presenting 52 countries, while Followers exhibit only 16 members. Leaders and Beginners present 27 and 23 countries, respectively. On the other hand, by dividing the nations into quartiles, this work decides to keep the number of members similar in each group. This fact explains part of the discrepancies that can be observed in Figure 3. For example, in Figure 3, Brazil, Argentina, and Russia shift from the OWSQ category of Moderate to the BoD classification of Follower. However, as seen in Table A.1, the rank positions of those nations did not alter significantly. Brazil is ranked 56th, Russia is 45th, and Argentina is 49th in the OWSQ approach. The BoD rank positions for these countries are 49th, 52nd, and 44th, respectively. That means that the changes in the number of elements in each category play a major role at the differences between the two categorisation methods.

A detailed visualization in the Africa map presented in Figure 4 exemplifies some discrepancies between the two classification strategies. This figure shows a set of Beginners in the OWSQ approach that present better classifications in the BoD technique. Two of them, Burundi and Lesotho, change to Follower and Angola, Guinea, Senegal and Mozambique shift to Moderate. The African countries typically present better outcomes for the Ecological Footprint (I12), notably due to the lower consumption of natural resources by their least developed economies. However, this specific group of countries additionally benefit from their performance in the Employee Engagement Index (I16), even if compared with the other nations from Africa. This effect explains the shift in category, a shift that is not evident in the OWSQ approach.

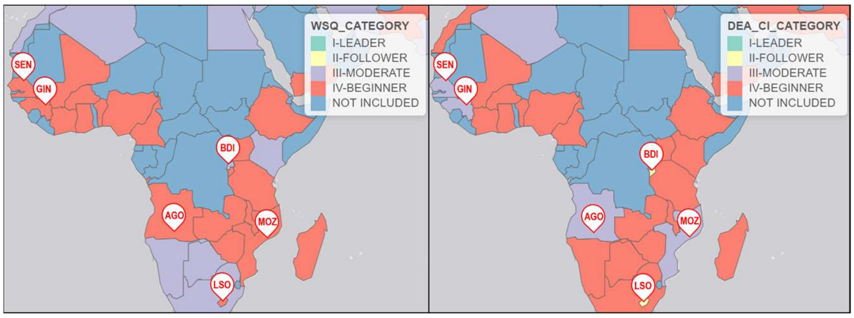


Figure 4 - Differences in OWSQ and BoD classification approaches - Examples in African countries.

Other discrepancies that can be explained by the use of different methodologies appear in a closer look in European countries. Figure 5 depicts the main changes between Leaders and Followers in Europe comparing OWSQ and BoD techniques. France switched from being a Leader in the OWSQ technique to being a Follower in the BoD method. In contrast, Hungary, Greece, and Romania switched from being Followers in the OWSQ method to being Leaders in the BoD method.

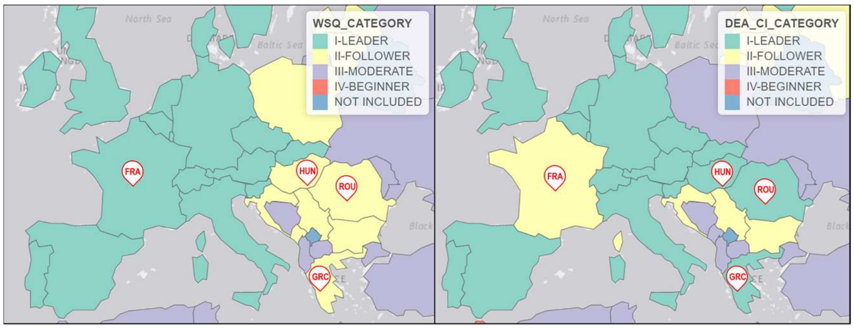


Figure 5 - Differences in OWSQ and BoD classification approaches - Examples in European countries.

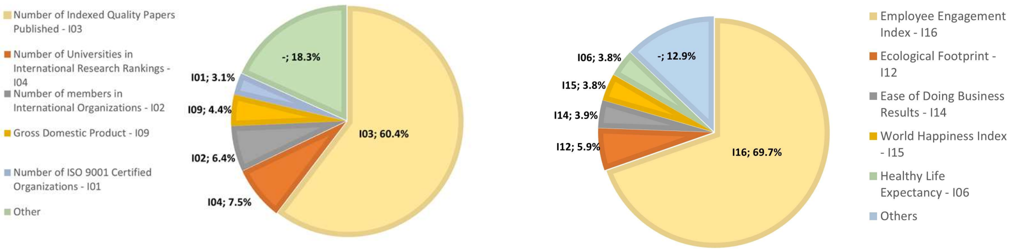
Considering a direct comparison between France and Hungary, Table 4 shows that France dropped from 22nd in OWSQ rank to 33rd in BoD, whereas Hungary rose from 34th in OWSQ to 18th in BoD approach. Examining the data with a higher level of detail, in Table 4, one can see the values of all observations and ranking order for all indicators in both countries. France outperforms Hungary in 11 out of the 16 indicators, but the order of magnitude of the value differences is lost when the values are converted in rank positions. In some cases, large discrepancies in ranking such as in Life Expectancy (I06), where France ranks 4 and Hungary ranks 50, account for less than 10% of the observation's difference. Another example is the Birth Mortality Rate, where a difference of 12 rank positions (20th for France, 32nd for Hungary) represents only 1.9% in the values. Looking at the indicators where Hungary excels, the situation of the Number of members of International Academy for Quality (I02) has the opposite impact. Hungary's performance is 20 times that of France, however the gap in rankings is just 21 places: Hungary is fourth and France is 25th. Therefore, the use of ranking positions to compose the OWSQ score plays a significant role in the differences between OWSQ and BoD techniques.

Table 4 - Comparison between performances of France and Hungary.

Code	Indicator	Observed value - 2018		Indicator Ranked Order	
		FRA	HUN	FRA	HUN
I01	Number of ISO 9001 Certified Organizations per 1,000 inhabitants	0.35	0.67	31	14
I02	Number of members of International Academy for Quality per 1,000 inhabitants	1.49×10^{-5}	3.07×10^{-4}	25	4
I03	Number of Indexed Quality Papers Published per 1,000 inhabitants	0.06	0.04	33	35
I04	Number of Universities in International Research Rankings per 1,000 inhabitants	2.98×10^{-4}	0	19	41
I05	Education Index (score)	0.84	0.82	25	32
I06	Healthy Life Expectancy (age)	73.40	66.80	4	50
I08	Global Competitiveness Index (score)	5.18	4.33	17	49
I09	Gross Domestic Product per capita (US dollars)	38476.66	14224.85	17	37
I11	Number of ISO 14001 Certified Organizations per 1,000 inhabitants	0.10	0.23	32	15
I13	Global Innovation Index (score)	54.40	44.90	14	29
I14	Ease of Doing Business Results (distance to frontier)	76.13	72.39	25	40
I15	World Happiness Index (score)	6.49	5.62	20	54
I16	Employee Engagement Index (%)	6.20	10.30	113	102
I07	Birth Mortality Rate (per 1,000 live births) - (Complement to 72.5)	69.30	68.10	20	32
I10	Gini Index (%) - (Complement to 64.8)	32.10	34.40	39	20
I12	Ecological Footprint (gha pc) - (Complement to 12.38)	7.69	8.78	93	77

5.2 Identification of strengths and weaknesses

We choose two nations with different performances as examples to analyse the different contributions of each indicator to their performance. The Netherlands' virtual weights are presented in Figure 6a, and Figure 6b represents the contributions of the indicators to Mozambique's performance.



(a) Virtual weights - The Netherlands

(b) Virtual weights - Mozambique

Figure 6: Contributions of the indicators for Mozambique and The Netherlands.

The most relevant strength of the Netherlands (Figure 6a) is the number of quality papers published (I03), which contributes to more than 60% of its performance, followed by the number of universities in international ranks (I04). These two metrics in the dimension Education account for 67.9% of the Netherlands' performance, demonstrating the country's attention in this field. Other strengths above the 4% threshold are the number of members in IAQ (I02) and the Gross Domestic Product (I09). Its main weaknesses are the Ecological Footprint (I12) and the Employee Engagement Index (I16) which contribute with less than 1% for the final score.

The example of Mozambique in Figure 6b shows that the most significant strength of this country is the Employee Engagement Index (I16), followed by the Ecological Footprint (I12), as previously discussed in Subsection 5.1. All the remaining virtual weights of Mozambique are below 4% indicating its poor performance compared to the efficiency frontier built by the BoD model. The Employee Engagement Index (I16) and the World Happiness Index (I15), both from the dimension Satisfaction, contribute for 73.5 percent of Mozambique's overall score, reflecting the country's achievements in this area.

5.3 Identification of peers and targets

Continuing with the Netherlands and Mozambique as examples, two separate clusters are chosen based on the geographic areas in which the nations are located, as defined by the United Nations Statistics Division (United Nations 2021). Two different BoD models will be computed in this analysis, one for each cluster. The clusters are used to create more uniform groups of countries for the identification of peers and targets so that the BoD model can be resolved for this smaller group.

In the case of the Netherlands, the model was computed using all the countries from Europe included in the WSQ Project. The CI scores and ranks for the countries under assessment in this cluster are presented in Table B.1 in Appendix B.

A BoD model was also solved considering the set of countries from the region of Sub-Saharan Africa, which includes Mozambique. Table B.2 in Appendix B displays the countries in this cluster, their CI scores and rank positions.

Table 5 presents the peers of the Netherlands and Mozambique, determined by the values of λ_j obtained from the results of optimisation model (2).

Table 5 - Peers and Targets Identification - Examples of the Netherlands and Mozambique for 2018.

			Peers			Peer
Code	Indicator	Netherlands 2018 results	Finland ($\lambda_j = 0.28$)	Switzerland ($\lambda_j = 0.82$)	Mozambique 2018 results	South Africa ($\lambda_j = 1$)
I01	Number of ISO 9001 Certified Organizations per 1,000 inhabitants	0.603	0.470	1.324	0.002	0.084
I02	Number of members of International Academy for Quality per 1,000 inhabitants	1.75×10^{-4}	3.79×10^{-4}	3.79×10^{-4}	0	3.53×10^{-5}
I03	Number of Indexed Quality Papers Published per 1,000 inhabitants	0.20	0.16	0.22	0	0.02
I04	Number of Universities in International Research Rankings per 1,000 inhabitants	7.00×10^{-4}	9.01×10^{-4}	9.01×10^{-4}	0	8.82×10^{-5}
I05	Education Index (score)	0.91	0.91	0.90	0.39	0.71
I06	Healthy Life Expectancy (age)	72.10	71.70	73.50	52.20	55.70
I07	Birth Mortality Rate (per 1,000 live births)	3.20	1.90	3.60	53.10	34.20
I08	Global Competitiveness Index (score)	5.66	5.49	5.86	2.89	4.32
I09	Gross Domestic Product per capita (US dollars)	48,223.16	45,703.33	73,271.97	415.72	6,160.73
I10	Gini Index (%)	29.30	27.10	32.50	54.00	63.00
I11	Number of ISO 14001 Certified Organizations per 1,000 inhabitants	0.16	0.26	0.37	0	0.02
I12	Ecological Footprint (gha pc)	5.92	6.09	4.85	0.87	3.42
I13	Global Innovation Index (score)	63.30	59.60	68.40	23.10	35.10
I14	Ease of Doing Business Results (distance to frontier)	76.03	80.37	75.92	54.00	64.89
I15	World Happiness Index (score)	7.44	7.63	7.49	4.42	4.72
I16	Employee Engagement Index (%)	12.20	12.20	13.20	28.00	15.30

The Netherlands' peers are Finland and Switzerland, which are considered efficient countries in the set selected. The Netherlands needs to look for the best practices of Finland and Switzerland, as those countries present a similar performance in macroquality compared to the Netherlands. The values of λ_j give the degree of similarity of the Netherlands and its peers. The targets for each indicator are determined looking at the results of the country's peers. For example, the Netherlands needs to nearly double its results for the number of members of International Academy for Quality (I02) to reach the values of Finland and Switzerland (3.79×10^{-4} members per 1,000 inhabitants), which represents the Netherlands' target for this indicator. In this case, both peers present better performance and may offer valuable insights on reaching the target. Notice that, even though I02 is considered a strength for the Netherlands in a worldwide context, a comparison within a more homogeneous group reveals other peers with better performance. In the case of the Global Innovation Index (I13), for instance, the results of the Netherlands are better than Finland's. Therefore, the Netherlands should look for Switzerland's practices to investigate potential improvements for this indicator. In this case, the Netherlands' target is 68.4, which is Switzerland's results.

The BoD model for the Sub-Saharan countries, only one country is identified as Mozambique's peer: South Africa. In this context, compared with Mozambique, the value of λ_j for South Africa equals one. Mozambique outperforms South Africa only in Employee Engagement Index (I16), Gini Index (I10) and Ecological Footprint (I12), so for all the other metrics, South Africa's results represent Mozambique's targets, and Mozambique may learn from South Africa's practices.

This kind of analysis represents one of the main advantages of the BoD technique compared to other strategies, since it may successfully provide direction on how the performance of a DMU can be enhanced by looking at best practices from their counterparts.

6 CONCLUSIONS

This work discusses an approach based on the Benefit-of-the-Doubt (BoD) technique to assess countries regarding their performance in quality, as an alternative to the method employed by the World State of Quality (WSQ) Project. A composite indicator (CI) resulting from the aggregation of 16 metrics is computed and the countries are ranked and categorised based on that. The similarities and discrepancies between both methods are discussed using the results of some countries as example. The results show that the BoD approach and the original method used by the WSQ Project present comparable results. Therefore, the proposed method can be alternatively employed for the WSQ Project presenting the advantage of being data-driven, so it is not necessary to judge the relative importance of the various metrics. In that sense, no country can complain about the resulting weights because they are obtained in the most favourable manner. Other than that, the data can be employed in their original form, requiring no transformations that can affect the analysis.

Another benefit of the BoD strategy is the identification of a country's strengths and weaknesses, which is discussed using illustrative examples. Furthermore, this strategy allows for the establishment of appropriate targets to steer the development of a country's performance as well as the identification of peers to serve as benchmarks. Countries from diverse geographical areas were presented as examples.

Future studies might look at using different measures to emphasize the many facets of a country's quality performance. Other research opportunities would be to look at the evolution of quality performance through time and to explore different approaches for countries' categorisation, such as a segmentation by continents.

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REFERENCES

Ahmed, S. M., Aoieong, R. T., Tang, S. L., and Zheng, D. X. M. (2005), “A comparison of quality management systems in the construction industries of Hong Kong and the USA”, International Journal of Quality and Reliability Management, Vol. 22 No. 2, pp. 149–161.

Aiginger, K. (1998), “A Framework for Evaluating the Dynamic Competitiveness of Countries”, Structural Change and Economic Dynamics, Vol. 9 No. 2, pp. 159–188.

Allen, R., Athanassopoulos, A., Dyson, R. G., and Thanassoulis, E. (1997), “Weights restrictions and value judgements in Data Envelopment Analysis: Evolution, development and future directions”, Annals of Operations Research, Vol. 73, Chapter 2, pp. 13–34.

Amado, C. A. F., São José, J. M. S., and Santos, S. P. (2016), “Measuring active ageing: A Data Envelopment Analysis approach”, European Journal of Operational Research, Vol. 255 No 1, pp. 207–223.

APQC, and ASQ (2013), “The ASQ Global State of Quality – Research – Discoveries 2013”, United States of America: American Society for Quality.

——— (2016), “The ASQ Global State of Quality – Research 2 – Discoveries 201.”, United States of America: American Society for Quality.

Bello-Pintado, A., and Merino-Díaz-de-Cerio, J. (2013), “Determinants of the use of quality management practices in Latin America: The case of Argentina and Uruguay”, Total Quality Management and Business Excellence, Vol. 24 No 1-2, pp. 31–47.

Bou-Llusar, J. C., Escrig-Tena, A. B., Roca-Puig, V., and Beltrán-Martín, I. (2009), “An empirical assessment of the EFQM Excellence Model: Evaluation as a TQM framework relative to the MBNQA Model”, Journal of Operations Management, Vol. 27 No 1, pp. 1–22.

Bowen, H. P., and Moesen, W. (2011), “Composite competitiveness indicators with endogenous versus predetermined weights: an application to the World Economic Forum’s Global Competitiveness Index”, Competitiveness Review: An International Business Journal.

Charnes, A., Cooper, W. W., and Rhodes, E. (1978), “Measuring the efficiency of decision making units”, European Journal of Operational Research, Vol. 2 No 6, pp. 429–444.

Chen, Y. Y., Wu, L., and Zhai, Q. G. (2019), “Does ISO 9000 certification benefit service firms?”, Sustainability (Switzerland), Vol. 11 No 21, pp. 1–22.

Cherchye, L., Moesen, W., Rogge, N., and Puyenbroeck, T. V. (2007), “An introduction to ‘Benefit of the Doubt’ composite indicators”, Social Indicators Research, Vol. 82 No 1, pp. 111–145.

Clegg, B., Roya G., and Mine O. (2013), "Quality management and performance: A comparison between the UK and Turkey", Production Planning and Control, Vol. 24 No 12, pp. 1015–1031.

Cubo, C., Saraiva, P., Sampaio, P., and Reis, M. (2019), "2017 World State of Quality: First Worldwide Results", Total Quality Management and Business Excellence, Vol. 32 No 304, pp. 1–10.

Dahlgaard, J. J., Kristensen, K., Kanji, G. K., Juhl, H. J., and Sohal, A. S. (1998), "Quality management practices: A comparative study between East and West", International Journal of Quality and Reliability Management, Vol. 15 No 8, pp. 812–826.

Dutta, S., Lanvin, B., and Wunsch-Vincent, S. (2020), Global Innovation Index 2020. Johnson Cornell University.

Farris, F. A. (2010), "The Gini index and measures of inequality", The American Mathematical Monthly, Vol. 117 No 10, pp. 851–864.

Gruetzmacher, S. B., Vaz, C. B., and Ferreira, A. P. (2021), "Performance Assessment of the Transport Sustainability in the European Union", Communications in Computer and Information Science, Vol. 1359, pp. 106–119.

Helliwell, J. F, Layard, R., Sachs, J. D., and De Neve, J. (2020), "World Happiness Report 2020.", New York: Sustainable Development Solutions Network.

Henriques, A. A., Camanho, A. S., Amorim, P., and Silva, J. G. (2020), "Performance benchmarking using composite indicators to support regulation of the Portuguese wastewater sector", Utilities Policy, Vol. 66: 101082.

Ismail, M. Y., M. Baradie, El, and Hashmi, M. S. J. (1998), "Quality Management in the Manufacturing Industry: Practice Vs Performance", Computers and Industrial Engineering, Vol. 35 No 3-4, pp. 519–522.

Jaeger, M., Adair, D., and Al-Qudah, S. (2013), "MBNQA criteria used in the GCC countries", The TQM Journal, Vol. 25 No 2, pp. 110–123.

Khalili, M., Camanho, A. S., Portela, M. C. A. S., and Alirezaee, M. R. (2010), "The measurement of relative efficiency using Data Envelopment Analysis with assurance regions that link inputs and outputs", European Journal of Operational Research, Vol. 203 No 3, pp. 761–770.

Lau, R. S. M., Zhao, X., and Xiao M. (2004), "Assessing quality management in China with MBNQA criteria", International Journal of Quality & Reliability Management.

Nardo, M., Saltelli, A., Tarantola S., Hoffmann A., and Giovannini E. (2008), Handbook on Constructing Composite Indicators: Methodology and User Guide. OECD; European Union; Joint Research Centre - European Commission.

Oliveira, R., Zanella A., and Camanho A. S (2020), "A temporal progressive analysis of the social performance of mining firms based on a Malmquist index estimated with a Benefit-of-the-Doubt directional model", Journal of Cleaner Production, Vol. 267: 121807.

Pereira, M. A., Camanho, A. S., Figueira, J. R., and Marques R. C. (2021). "Incorporating preference information in a range directional composite indicator: The case of Portuguese public hospitals", European Journal of Operational Research, Vol. 294 No 2, pp. 633–650.

Qazi, T. F., Niazi A. A. K., Asghar W., and Basit A. (2021), "Ease of Doing Business: analysis of trade facilitations of one hundred twenty-seven countries of the world", Journal of Accounting and Finance in Emerging Economies, Vol. 7 No 1, pp. 65–75.

Rogge, N. (2018), "Composite indicators as generalized benefit-of-the-doubt weighted averages", European Journal of Operational Research, Vol 267 No 1, pp. 381–392.

Rogge, N., and Archer G. (2021), "Measuring and analyzing country change in establishing ease of doing business using a revised version of World Bank's Ease of Doing Business Index", European Journal of Operational Research, Vol. 290. pp. 373–385.

Sampaio, P., Saraiva P., Cubo C. and Reis, M. (2018). "From another quality dimension", Quality Progress, Vol. 51 No 12, pp. 50–57.

Saraiva, P., Sampaio P., Cubo C., and Reis M. (2020), "Macroquality Measurement: World State of Quality and European Quality Scoreboard approaches and results", Total Quality Management and Business Excellence, Vol. 31, No 9-10, pp. 1060–1076.

Saraiva, P., Sampaio, P., Cubo, C., Reis, M., & d'Orey, J. (2018). 2018 World State of Quality (Final Report). University of Minho and University of Coimbra, Portugal. Available at http://wsq.dps.uminho.pt/.

United Nations (2021). "UNSD - Methodology. Standard country or area codes for statistical use (M49). UN Department of Economic and Social Affairs. Statistics Division. Standard Country or Area Codes for Statistical Use (M49). UN Department of Economic; Social Affairs. Statistics Division.

Van Iwaarden, J., Van Der Wiele, T., Dale, B., Williams, R., and Bertsch, B. (2008), "The Six Sigma improvement approach: a transnational comparison", International Journal of Production Research, Vol. 46 No 23, pp. 6739–6758.

Van Puyenbroeck, T., Montalto V., and Saisana M. (2021), “Benchmarking culture in Europe: A Data Envelopment Analysis approach to identify city-specific strengths”, European Journal of Operational Research, Vol. 288 No 2, pp. 584–597.

Van Puyenbroeck, T., and Rogge N. (2020), “Comparing regional human development using global frontier difference indices”, Socio-Economic Planning Sciences, Vol. 70, pp. 1–8.

Verbunt, P., and Rogge N. (2018), “Geometric composite indicators with compromise Benefit-of-the-Doubt weights”, European Journal of Operational Research, Vol. 264 No 1, pp. 388–401.

Zanella, A., Camanho A. S., and Dias T. G. (2013), “Benchmarking countries’ environmental performance”, Journal of the Operational Research Society, Vol. 64 No 3, pp. 426–438.

Zanella, A., Camanho A. S., and Dias, T. G. (2015), “Undesirable outputs and weighting schemes in composite indicators based on data envelopment analysis”, European Journal of Operational Research, Vol. 245 No 2, pp 517–530.

APPENDICES

Appendix A - Comparison between BoD and OWSQ techniques

Table A.1 - Composite Indicator - Comparison BoD and OWSQ techniques.

		OWSQ Approach			BoD using OWSQ weights		BoD using flexible weights ≥ 4%		
Country	Code	Score	Rank Position	Category	Composite Indicator	Rank Position	Composite Indicator	Rank Position	Category
Albania	ALB	52.82	52	Moderate	0.31	58	0.40	68	Moderate
Algeria	DZA	71.39	82	Moderate	0.26	88	0.36	85	Moderate
Angola	AGO	85.08	103	Beginner	0.23	105	0.42	64	Moderate
Argentina	ARG	50.56	49	Moderate	0.38	40	0.49	44	Follower
Armenia	ARM	60.02	65	Moderate	0.30	67	0.41	66	Moderate
Australia	AUS	23.52	7	Leader	0.75	4	0.88	6	Leader
Austria	AUT	26.89	12	Leader	0.62	16	0.66	23	Leader
Azerbaijan	AZE	63.50	72	Moderate	0.27	80	0.44	59	Follower
Bangladesh	BGD	75.33	92	Moderate	0.27	81	0.44	56	Follower
Belgium	BEL	30.66	18	Leader	0.63	14	0.70	20	Leader
Benin	BEN	93.02	117	Beginner	0.19	118	0.31	116	Beginner
Bhutan	BTN	78.69	96	Beginner	0.23	103	0.29	118	Beginner
Bolivia	BOL	75.10	91	Moderate	0.26	89	0.41	65	Moderate
Bosnia-Herzegovina	BIH	56.62	58	Moderate	0.33	49	0.39	76	Moderate
Botswana	BWA	72.74	84	Moderate	0.25	96	0.33	111	Beginner
Brazil	BRA	55.68	56	Moderate	0.32	52	0.47	49	Follower
Bulgaria	BGR	44.19	40	Follower	0.43	33	0.51	38	Follower
Burkina Faso	BFA	92.76	116	Beginner	0.20	117	0.32	115	Beginner
Burundi	BDI	88.90	114	Beginner	0.23	101	0.45	55	Follower
Cambodia	KHM	75.64	93	Moderate	0.26	85	0.36	93	Beginner
Cameroon	CMR	88.54	113	Beginner	0.21	110	0.33	110	Beginner
Canada	CAN	26.89	11	Leader	0.58	19	0.71	19	Leader
Chile	CHL	40.24	31	Follower	0.40	37	0.56	28	Leader
China	CHN	53.03	54	Moderate	0.34	44	0.40	71	Moderate
Colombia	COL	48.78	44	Moderate	0.35	42	0.54	31	Follower
Costa Rica	CRI	44.22	41	Follower	0.34	45	0.50	41	Follower
Cote d'Ivoire	CIV	87.18	109	Beginner	0.20	115	0.32	112	Beginner
Croatia	HRV	41.15	35	Follower	0.46	30	0.51	36	Follower
Cyprus	CYP	37.51	29	Follower	0.41	35	0.46	51	Follower
Czech Republic	CZE	27.82	13	Leader	0.54	22	0.74	14	Leader
Denmark	DNK	21.95	5	Leader	0.68	8	0.82	8	Leader
Dominican Republic	DOM	67.22	77	Moderate	0.29	72	0.47	47	Follower
Ecuador	ECU	58.46	62	Moderate	0.30	62	0.46	53	Follower
Egypt	EGY	72.13	83	Moderate	0.27	82	0.35	99	Beginner
El Salvador	SLV	63.34	70	Moderate	0.30	63	0.49	43	Follower
Estonia	EST	29.03	16	Leader	0.62	15	0.75	13	Leader
Ethiopia	ETH	89.96	115	Beginner	0.22	108	0.33	109	Beginner
Finland	FIN	20.83	4	Leader	0.84	3	0.94	4	Leader
France	FRA	32.89	22	Leader	0.48	28	0.52	33	Follower
Georgia	GEO	53.05	55	Moderate	0.31	55	0.43	63	Moderate
Germany	DEU	24.17	9	Leader	0.61	18	0.65	24	Leader
Ghana	GHA	80.46	99	Beginner	0.24	97	0.33	106	Beginner
Greece	GRC	42.23	37	Follower	0.51	26	0.56	27	Leader
Guatemala	GTM	67.62	78	Moderate	0.28	76	0.44	60	Moderate
Guinea	GIN	87.63	112	Beginner	0.22	109	0.39	75	Moderate
Honduras	HND	69.99	81	Moderate	0.28	75	0.46	54	Follower
Hungary	HUN	40.57	34	Follower	0.56	21	0.71	18	Leader
India	IND	68.24	79	Moderate	0.26	87	0.36	87	Moderate
Indonesia	IDN	65.07	74	Moderate	0.28	79	0.36	88	Moderate
Iran	IRN	63.60	73	Moderate	0.30	66	0.36	91	Beginner
Ireland	IRL	23.73	8	Leader	0.68	7	0.81	9	Leader
Israel	ISR	27.93	14	Leader	0.66	10	0.74	15	Leader
Italy	ITA	34.24	27	Leader	0.64	11	0.94	5	Leader
Jamaica	JAM	56.72	59	Moderate	0.31	59	0.51	40	Follower
Japan	JPN	32.05	20	Leader	0.49	27	0.55	30	Follower
Jordan	JOR	57.85	60	Moderate	0.30	68	0.37	83	Moderate
Kazakhstan	KAZ	50.75	50	Moderate	0.33	50	0.49	42	Follower
Kenya	KEN	74.45	89	Moderate	0.25	93	0.35	97	Beginner
Kyrgyzstan	KGZ	68.89	80	Moderate	0.29	70	0.51	39	Follower

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		OWSQ Approach			BoD using OWSQ weights		BoD using flexible weights ≥ 4%		
Country	Code	Score	Rank Position	Category	Composite Indicator	Rank Position	Composite Indicator	Rank Position	Category
Latvia	LVA	40.32	32	Follower	0.40	36	0.46	50	Follower
Lebanon	LBN	61.51	68	Moderate	0.31	61	0.37	81	Moderate
Lesotho	LSO	84.29	102	Beginner	0.21	111	0.44	57	Follower
Lithuania	LTU	41.38	36	Follower	0.43	34	0.49	45	Follower
Luxembourg	LUX	33.37	24	Leader	0.52	25	0.72	17	Leader
Macedonia	MKD	50.31	48	Moderate	0.33	47	0.40	69	Moderate
Madagascar	MDG	86.36	106	Beginner	0.24	98	0.34	100	Beginner
Malawi	MWI	86.56	107	Beginner	0.23	104	0.34	101	Beginner
Malaysia	MYS	42.61	38	Follower	0.39	38	0.44	58	Follower
Mali	MLI	87.61	111	Beginner	0.20	116	0.32	113	Beginner
Malta	MLT	32.55	21	Leader	0.63	13	1.00	1	Leader
Mauritius	MUS	49.79	47	Moderate	0.32	53	0.38	78	Moderate
Mexico	MEX	49.47	46	Moderate	0.31	57	0.41	67	Moderate
Moldova	MDA	57.98	61	Moderate	0.30	69	0.39	74	Moderate
Mongolia	MNG	65.31	75	Moderate	0.26	86	0.48	46	Follower
Montenegro	MNE	45.79	43	Follower	0.34	46	0.40	70	Moderate
Morocco	MAR	63.41	71	Moderate	0.28	77	0.36	90	Beginner
Mozambique	MOZ	87.39	110	Beginner	0.22	107	0.38	80	Moderate
Namibia	NAM	73.51	87	Moderate	0.25	94	0.35	94	Beginner
Nepal	NPL	74.68	90	Moderate	0.26	84	0.36	89	Moderate
Netherlands	NLD	23.22	6	Leader	0.73	5	0.80	10	Leader
Nicaragua	NIC	73.10	85	Moderate	0.27	83	0.35	98	Beginner
Nigeria	NGA	86.10	105	Beginner	0.20	113	0.33	108	Beginner
Norway	NOR	19.54	3	Leader	0.73	6	0.84	7	Leader
Pakistan	PAK	79.06	97	Beginner	0.21	112	0.34	103	Beginner
Panama	PAN	51.06	51	Moderate	0.33	48	0.55	29	Leader
Paraguay	PRY	74.24	88	Moderate	0.26	90	0.31	117	Beginner
Peru	PER	56.08	57	Moderate	0.30	65	0.39	77	Moderate
Philippines	PHL	59.37	64	Moderate	0.31	60	0.51	35	Follower
Poland	POL	37.67	30	Follower	0.38	39	0.44	61	Moderate
Portugal	PRT	33.11	23	Leader	0.67	9	0.73	16	Leader
Romania	ROU	37.49	28	Follower	0.47	29	0.60	26	Leader
Russia	RUS	48.85	45	Moderate	0.32	51	0.46	52	Follower
Rwanda	RWA	75.84	94	Moderate	0.25	91	0.35	96	Beginner
Senegal	SEN	79.06	98	Beginner	0.25	95	0.38	79	Moderate
Serbia	SRB	40.42	33	Follower	0.43	32	0.51	37	Follower
Slovakia	SVK	33.82	26	Leader	0.54	24	0.77	11	Leader
Slovenia	SVN	29.20	17	Leader	0.61	17	0.69	21	Leader
South Africa	ZAF	65.34	76	Moderate	0.29	73	0.35	95	Beginner
South Korea	KOR	33.40	25	Leader	0.44	31	0.51	39	Follower
Spain	ESP	31.86	19	Leader	0.54	23	0.61	25	Leader
Sri Lanka	LKA	58.97	63	Moderate	0.31	56	0.53	32	Follower
Sweden	SWE	19.37	2	Leader	0.88	2	0.96	3	Leader
Switzerland	CHE	19.30	1	Leader	1.00	1	1.00	1	Leader
Tajikistan	TJK	76.93	95	Moderate	0.25	92	0.36	92	Beginner
Tanzania	TZA	82.79	101	Beginner	0.23	100	0.34	102	Beginner
Thailand	THA	43.68	39	Follower	0.34	43	0.44	62	Moderate
Tunisia	TUN	62.00	69	Moderate	0.30	64	0.37	82	Moderate
Turkey	TUR	52.88	53	Moderate	0.32	54	0.37	84	Moderate
Uganda	UGA	85.16	104	Beginner	0.23	99	0.34	104	Beginner
Ukraine	UKR	61.14	66	Moderate	0.29	71	0.40	72	Moderate
United Kingdom	GBR	25.78	10	Leader	0.64	12	0.67	22	Leader
United States	USA	28.22	15	Leader	0.58	20	0.76	12	Leader
Uruguay	URY	44.82	42	Follower	0.37	41	0.52	34	Follower
Venezuela	VEN	73.14	86	Moderate	0.28	78	0.40	73	Moderate
Vietnam	VNM	61.22	67	Moderate	0.28	74	0.36	86	Moderate
Yemen	YEM	93.90	118	Beginner	0.20	114	0.32	114	Beginner
Zambia	ZMB	82.20	100	Beginner	0.23	102	0.34	105	Beginner

Zimbabwe	ZWE	86.86	108	Beginner	0.22	106	0.33	107	Beginner

Appendix B - Composite indicators generated to analyse countries' performance within clusters

Table B.1 - Composite Indicator - Cluster of countries from Europe.

Country	Code	Composite Indicator	Rank Position
Albania	ALB	0.92	12
Austria	AUT	0.83	26
Belgium	BEL	0.88	17
Bosnia-Herzegovina	BIH	0.75	33
Bulgaria	BGR	0.85	24
Croatia	HRV	0.79	30
Czech Republic	CZE	0.86	21
Denmark	DNK	0.92	13
Estonia	EST	1.00	1
Finland	FIN	1.00	1
France	FRA	0.74	34
Germany	DEU	0.85	23
Greece	GRC	0.78	31
Hungary	HUN	0.86	19
Ireland	IRL	0.89	15
Italy	ITA	1.00	1
Latvia	LVA	0.72	36
Lithuania	LTU	0.73	35
Luxembourg	LUX	0.86	22
Macedonia	MKD	0.86	20
Malta	MLT	1.00	1
Moldova	MDA	0.82	27
Montenegro	MNE	0.81	29
Netherlands	NLD	0.90	14
Norway	NOR	0.98	8
Poland	POL	0.71	37
Portugal	PRT	0.93	11
Romania	ROU	0.98	9
Russia	RUS	1.00	1
Serbia	SRB	0.96	10
Slovakia	SVK	0.87	18
Slovenia	SVN	0.88	16
Spain	ESP	0.81	28
Sweden	SWE	0.99	7
Switzerland	CHE	1.00	1
Ukraine	UKR	0.75	32
United Kingdom	GBR	0.85	25

Table B.2 - Composite Indicator - Cluster of countries from Sub-Saharan Africa.

Country	Code	Composite Indicator	Rank Position
Angola	AGO	0.29	7
Benin	BEN	0.20	26
Botswana	BWA	0.48	3
Burkina Faso	BFA	0.27	15
Burundi	BDI	0.29	8
Cameroon	CMR	0.22	25
Cote d'Ivoire	CIV	0.25	20
Ethiopia	ETH	0.26	18
Ghana	GHA	0.28	13
Guinea	GIN	0.29	6
Kenya	KEN	0.27	16
Lesotho	LSO	0.29	5
Madagascar	MDG	0.25	21
Malawi	MWI	0.24	23
Mali	MLI	0.29	9
Mauritius	MUS	1.00	1
Mozambique	MOZ	0.25	19
Namibia	NAM	0.37	4
Nigeria	NGA	0.24	22
Rwanda	RWA	0.28	10
Senegal	SEN	0.28	11
South Africa	ZAF	1.00	1
Tanzania	TZA	0.28	12
Uganda	UGA	0.27	14
Zambia	ZMB	0.23	24
Zimbabwe	ZWE	0.26	17

Multiple Management Systems in pursue of Eco-Product Innovation: The role of slack resources

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STRUCTURED ABSTRACT

Purpose – The aim of this article is to analyze the moderating effect of slack resources in the relationship between the adoption of multiple management systems (MSs) on eco-product innovation (EPI).

Methodology – Quality, Environmental and Occupational Health & Safety MSs certifications were analyzed. Gathering data from the Eikon Database, a longitudinal analysis of 2,859 European and Asian firms was performed including years 2006 – 2020.

Findings – Results suggest that environmental MSs act as the main driver of EPI. Moreover, slack resources' effect on EPI is found to be moderated by that of MSs. More specifically, slack resources strengthen the impact of multiple certifications that include EMSs in combination with other MSs. Nonetheless, if environmental MSs are adopted alone, EPI decreases as slack resources increase.

Research implications and limitations – The adoption of single or multiple MSs does not assure a better performance in terms of EPI. Nonetheless, environmental MSs seem to be key drivers to promote EPI but at the same time they might hinder it in firms with large slack resources. Further research is needed to disentangle the existing trade-offs to this end, including other variables that are not considered in depth in this study such specific stakeholders' engagement (clients, community, suppliers, among others).

Originality – This is one of the first articles to analyze simultaneously the quality, environmental and occupational health & safety MSs on EPI, also including the moderating role of slack resources. Moreover, considering a wide time spam and including companies from different backgrounds provides insightful findings within this field.

Keywords: Management Systems, Certifications, Eco-product innovation, Slack Resources.

Paper type: Research paper

1. INTRODUCTION

Sustainable development is increasingly catching the attention of governments, companies, customers, and society in general. To face with this new reality, different managerial practices have been discussed in literature including, among others, sustainable R&D (Cuerva *et al.*, 2014), environmental management systems (Wagner, 2008), and whole supply chains (Daddi *et al.*, 2021).

One of the most widely implemented practices within organizations are Management Systems (MSs). In fact, there is a constant growth of ISO 9001 and ISO 14001 certifications of quality and environmental MSs (ISO, 2021). The latter have been considered eco-innovations by themselves (Wang *et al.,* 2022), but their impact varies substantially depending on the motivations that led to their implementation. In this line, Heras-Saizarbitoria and Borial (2013) present an exhaustive review discussing the potential benefits of both ISO 9001 and 14001 and their relationship with other managerial practices. Although the literature relating MSs and innovation is still growing and requires further analysis, some studies suggest that the implementation of multiple MSs lead to innovation benefits (see e.g., Bernardo, 2014; Hernandez-Vivanco *et al.*, 2016), including sustainable innovation (see e.g., Hernandez-Vivanco *et al.*, 2018). Nonetheless, how MSs are related to sustainable innovation remains in a exploratory phase with non-conclusive results as their effect has different implications according to the existing literature (Hojnik and Ruzzier, 2016).

Investing in eco-product innovation (EPI) can be risky and therefore firms might require having a cushion of resources named slack resources to innovate accordingly (Bourgeois, 1981). Slack resources are the result of previous financial performance (Voss *et al.*, 2008) and, since MSs leverages it (Hernandez-Vivanco *et al.*, 2019), they might have a role on how slack resources are used towards EPI.

Thus, the aim of this paper is to analyze the impact of MSs on EPI. Specifically, ISO 14001 for environment, ISO 9001 for quality and OHSAS 18001 for occupational, health and safety management. Analyzing together the different combinations of implementation of these MSs and the role of slack resources, as to the best of the authors' knowledge, has been mostly neglected in the existing literature. According to the results obtained, companies implementing the three MSs obtained higher levels of eco-innovation. Moreover, slack resources increase the effect of multiple certifications on EPI whenever the ISO 14001 is included. Nonetheless, firms holding only the ISO 14001 innovate better at lower levels of slack resources.

2. LITERATURE REVIEW

2.1. Management systems and eco-product innovation

The analysis related to eco-innovation is being increasingly studied in the last years as a different type of innovation compared to that of general, or traditional innovation. According to different literature review papers such as Hojnik and Ruzzier (2016) and Oduro *et al.* (2021), eco-innovation has important managerial implications including the increase of competitive advantage driven by the required management and policy factors implemented by companies that adopt eco-innovation.

The concept itself of eco-innovation has been defined in different ways (Hojnik and Ruzzier, 2016). Kemp and Pearson (2007), discuss that eco-innovation fosters the “reduction of environmental risk, pollution and the negative impacts of resources use (including energy use) compared to relevant alternatives.” Horbach *et al.* (2012), add that the “positive environmental effects can be explicit goals or side effects of innovations”, which can occur internally or externally through company’s stakeholders, specially customers (see also Al-Shami and Rashid, 2022; Carrillo-Hermosilla *et al.*, 2010). Altogether, the Eco-Innovation Observatory (2010), refers to eco-innovation as the “introduction of any new or significantly improved product (good or service), process, organizational change or marketing solution that reduces the use of natural resources (including materials, energy, water and land) and decreases the release of harmful substances across the whole life cycle.” Therefore, eco-innovation allows reducing the negative environmental effects of business by increasing the efficiency of using resources within organizations (Hojnik and Ruzzier, 2016)

Analogous to the general framework of innovation, there are different types of eco-innovation driven by different practices; namely, product, process, organizational and marketing methods. According to the review done by Hojnik and Ruzzier (2016), the main drivers of eco-innovation include regulations and market pull factors, followed, although with a significant distance, by cost savings, firm size, research and development (R&D), environmental management systems (EMS), stakeholders’ environmental pressure, ISO 14001 certification, supply chain pressure, image improvement, competitive advantage gained, past introduction of innovation, and corporate social responsibility. Conversely, technology-specific instruments, economic risk and uncertainty, shareholders’ pressure, total quality management practices, ISO 9001 certification for quality management are found to be related to eco-innovation, although they are not directly its drivers.

Related to the aforementioned factors, significant differences have been found in the required capabilities that enable general innovation and eco-innovation (Cueva *et al.* 2014). Moreover, differences between small and large companies have been found in the existing literature (Álvarez Gil *et al.*, 2001; Hofer *et al.*, 2012; Kesidou and Demirel, 2012). Triguero *et al.* (2016) pointed out that the demand on green products as well as the implementation of eco-organizational innovation have a positive impact on eco-innovation. Regarding the green supply chain management, Daddi *et al.* (2021) found a positive relationship between the internalization of EMS and firm performance. More recently, Wang *et al.* (2022) identified circular economy not only as complementary to eco-innovations, but also as relevant driver. Thus, the implementation of eco-innovation could also lead to sustainable business performance (Fernando *et al.*, 2019).

The implementation of MSs has more recently been analyzed as a factor that might have positive impacts on eco-innovation. Quality MSs have been observed to act as catalyzers of eco-innovation in some organizations (Cuerva *et al.*, 2014). Moreover, Hojnik and Ruzzier (2016) show that ISO 14001 plays a significant role enhancing eco-innovation in more substantial ways compared to other MSs such as ISO 9001 or Eco-Management and Audit Scheme (EMAS). García-Quevedo *et al.* (2020) took a different path to analyze the impact of ISO 9001 and ISO 14001 on eco-innovation, and highlighted the importance of the adoption of MSs, mainly ISO 14001 and ISO 9001. Similarly, Wang *et al.* (2022) conclude that environmental MS could facilitate the generation or adoption of eco-innovation within organizations (see also Daily and Huang, 2001; Montobbio and Solito, 2018; Ramus, 2002; Rennings and Rammer, 2011; Wagner, 2008). Consequently, companies holding an environmental MS attain better results in terms of sustainable performance (Al-Shami and Rashid, 2022; Rehfeld *et al.,* 2007).

Although environmental MSs are found to be drivers of eco-innovation, other MSs could also be implemented in combination with them, such as ISO 9001, ISO 45001/former OHSAS 18001 (for occupational health and safety), SA 8000 (for social responsibility), etc. Thus, companies could have multiple management systems in place. Implementing more than one MS can have various benefits (see e.g., Bernardo *et al.*, 2015), including general innovation (Bernardo, 2014; Hernandez-Vivanco *et al.*, 2016) and sustainability through product innovation (Hernandez-Vivanco *et al.*, 2018). Thus, the existing literature, suggests that, within the analyzed certifications, ISO 14001 is the main driver towards EPI. On the other hand, ISO 9001 and OHSAS 18001 by themselves are not key drivers but might be related to EPI so they neither promote or hinder EPI. Consequently, H1 is formulated as follows:

H1a: The ISO 14001 certification promotes eco-product innovation either when implemented in a single or multiple certification structure

H1b: The ISO 9001 and OHSAS 18001 do not have an impact on eco-product innovation if not implemented in combination with the ISO 14001 certification

2.2. The role of slack resources

The adoption of environmental strategy requires the involvement of customers and employees, as well as a strong environmental concern within firms, including that of managers and shareholders. Thus, a shared vision is necessary to use existing resources that spur EPI (Hojnik and Ruzzier, 2016).

Deploying resources in new projects can be a real challenge specially for firms facing a large scarcity of available reserves (Nohria and Gulati, 1996). Therefore, EPI requires some slack resources, even for firms aiming at minimizing slack for the sake of efficiency (Tan and Peng, 2003). Moreover, it is worth noticing that slack resources are the result of previous financial performance (Nohria and Gulati, 1996; Voss *et al.*, 2008). In this sense, good environmental performance is a consequence of earlier good financial performance (Testa and D'Amato, 2017).

Although slack resources are consistently associated to increased environmental performance, having slack resources is not a guarantee for firms to engage in EPI projects. In fact, some firms might even prefer using their slack resources for paying legal and economic sanctions rather than to engage in risky environmental projects (Berrone *et al.*, 2013). One way to avoid this is by investing in the relationship with firms' stakeholders including customers, the environment and employees (Waddock and Graves, 1997). In such cases, firms with larger slacks are more prone to be proactive in terms of responding to stakeholders' needs. Conversely, firms not performing so well would be rather reactive by limiting to meet stakeholders' minimum standards (Arora and Dharwadkar, 2011). Therefore, it seems that for firms to engage resources in EPI both are necessary: i) attaining a consistent and healthy financial performance and ii) investing in the relationship with customers and employees to promote a shared view that is favorable to eco-innovation.

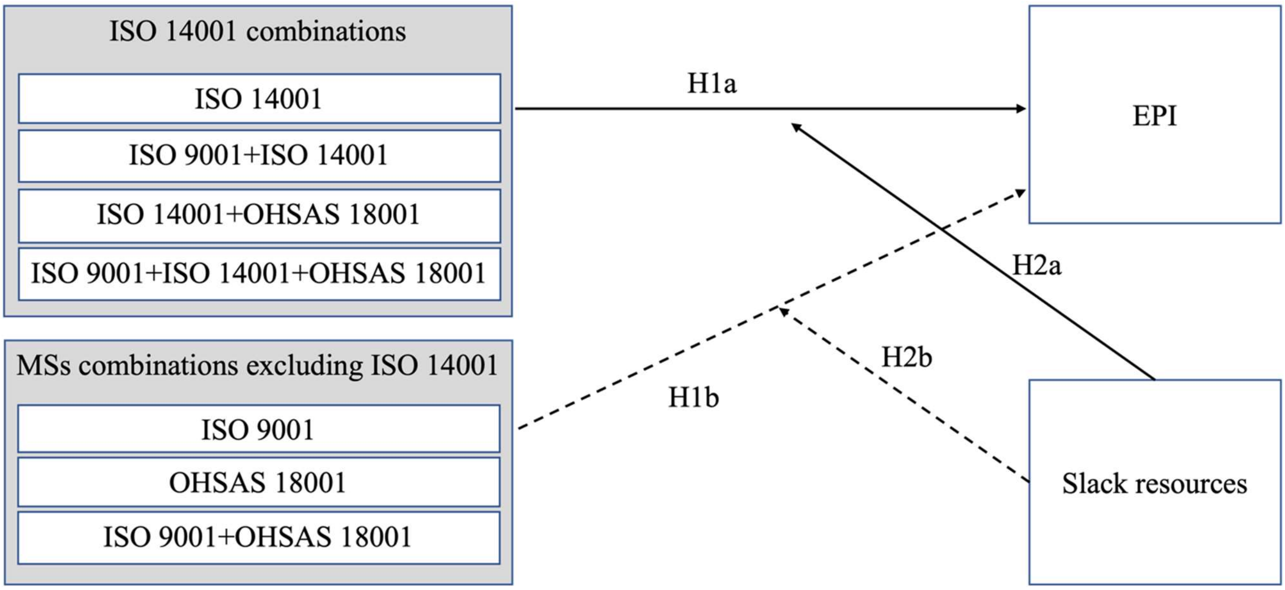
According to Hernandez-Vivanco *et al.* (2019), the ISO 9001 certification is a key driver to promote a sustained financial performance as it continuously and persistently promote its accomplishment even when implemented in combination with ISO 14001 and OHSAS 18001. The ISO 9001 certification promotes customers satisfaction as its main objective, but it also has positive effects on employees' performance and safety (Naveh and Marcus, 2007), as so would do the OHSAS 18001 certification (Lo *et al.*, 2014). Although the ISO 9001 and OHSAS 18001 seem to be aligned towards engaging customers and employees (although perhaps at different levels), they lack the environmental vision which can be provided by the ISO 14001 certification, as proposed in H1. Instead, the ISO 14001 is not a driver by itself of financial performance (Hernandez-Vivanco *et al.*, 2019) and, in some cases, it might even lead to negative outcomes in these terms (Wagner *et al.*, 2002). Thus, for slack resources to be deployed in benefit of EPI, the ISO 14001 certification seems relevant when implemented in combination with the ISO 9001 and/or the OHSAS 18001. Consequently, H2 is developed as follows:

H2a: Slack resources moderate positively the effect of certifications on eco-innovation, in firms holding ISO 14001 in combination with ISO 9001 and/or OHSAS 18001.

H2b: Slack resources do not moderate the effect of single certifications, or multiple certifications that exclude ISO 14001, on eco-product innovation.

Figure 1 schematizes the studied relationships.

Figure 1. Model relating certifications, slack resources, and eco-product innovation



The dotted line represents relationships that are expected to be non-significant.

3. RESEARCH METODOLOGHY

3.1. Sample selection

The analysis is based on the Thomson Reuters' Refinitiv® Eikon database, which collects and classifies the firms' information from more than 180 countries. This database also provides a rank of each individual dimension in each of the existing 18 categories, such as "Product Responsibility". This database also includes the certification dynamics of ISO 9001, ISO 14001 and OHSAS 18001 which are of special interest to this research as the most relevant QMS, EMS and OHSMSs, respectively. Therefore, only firms including information about these certifications, along with non-missing values of the other variables were included. The analyzed sample consists of 2,938 firms with observations between years 2006 and 2020.

3.2. Variables measurement

For every firm i=1,…, 2938 and year t=2006,…,2020, the variables were measured as detailed next in this section.

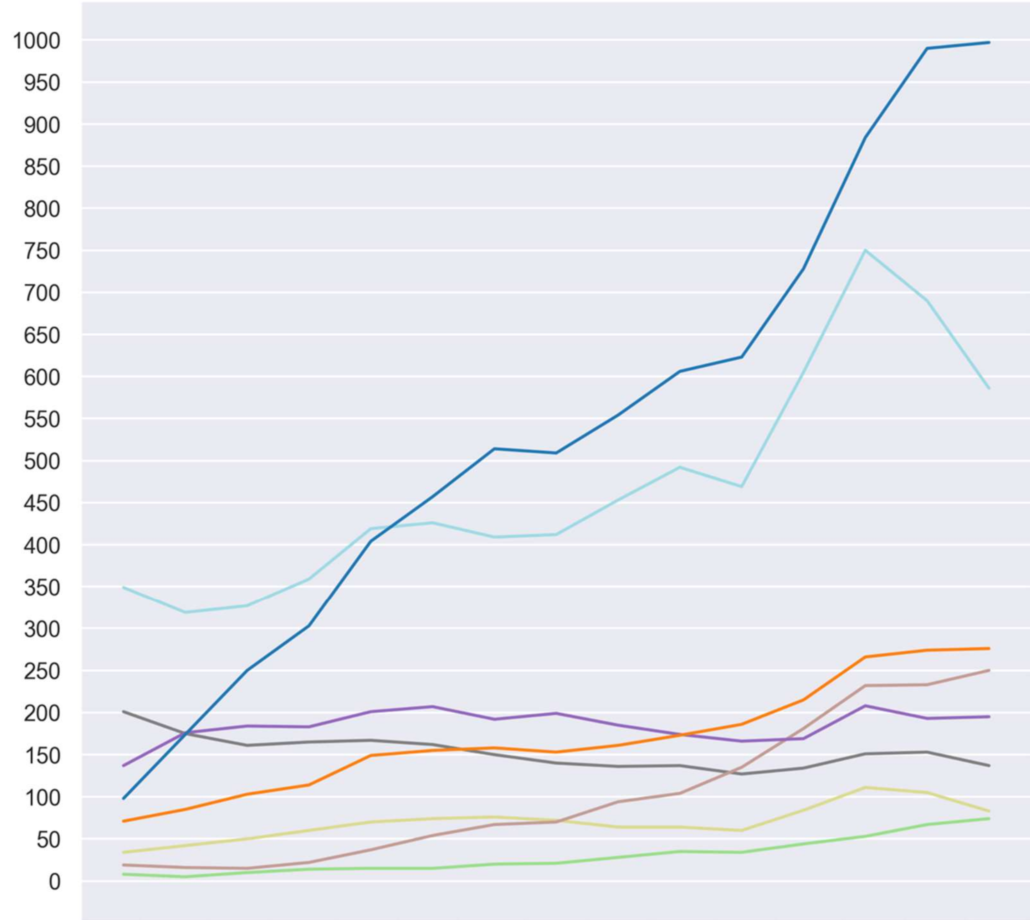
The dependent variable, EPI, was constructed as the sum of the different dimensions of eco-product innovation included in the Eikon database (Papagiannakis *et al.*, 2019). Such dimensions are related to the design, production, and sales of EPI.

Regarding the independent variables, there two main concepts that need to be considered. Firstly, MSs certifications were measured as a categorical variable composed of: 0. No certification, 1. ISO 9001, 2. ISO 14001, 3. OHSAS 18011, 4. ISO 9001 + ISO 14001, 5. ISO 9001 + OHSAS 18001, 6. ISO 14001 + OSHSAS 18001 and 7. Triple (i.e., ISO 9001 + ISO 14001 + OHSAS 18001) (Hernandez-Vivanco *et al.*, 2019). Secondly, slack resources are measured as the ratio Total current assets/total current liabilities to represent the relation between the amount of available resources with the amount of debts or obligations that should be paid to creditors within a particular year (Papagiannakis *et al.*, 2019).

Finally, control variables were included. Firstly, as pointed out by Heras-Saizarbitoria and Boiral (2013), stakeholder involvement is relevant not only in the context of the adoption of ISO 9001 and ISO 14001 certifications, but also to innovation. This variable was taken directly from the Eikon database which ranks each firm to score their performance in this dimension between 0 and 100. Moreover, firms' commitment to innovate considering health & safety, integrity and data privacy is closely related to EPI (Papagiannakis *et al.*, 2019) and it was taken directly from the Eikon ranked variable Product Responsibility Score. Finally, the investment in R&D as well as firm size were controlled (Papagiannakis *et al.*, 2019).

4. RESULTS

The certification dynamics throughout the studied years can be visualized in Figure 1. It is evidenced that there is a clear pattern of firms to adopt increasingly the triple certifications, whereas not having any certification seems to be in a decline stage, especially in the last years. The trend for double certifications is also increasing while that of single certifications seem to be steadier across the analyzed years.



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
None	349	319	327	359	419	426	409	412	453	492	469	605	750	690	586
ISO9001	34	42	50	60	70	74	76	72	64	64	60	84	111	105	83
ISO14001	201	175	161	165	167	162	150	140	136	137	127	134	151	153	137
OHSAS18001	19	16	15	22	37	54	67	70	94	104	135	181	232	233	250
ISO9001+ISO14001	137	176	184	183	201	207	192	199	185	174	166	169	208	193	195
ISO9001+OHSAS18001	8	5	10	14	15	15	20	21	28	35	34	44	53	67	74
ISO14001+OHSAS18001	71	85	103	114	149	155	158	153	161	173	186	215	266	274	276
Triple	98	174	250	303	404	457	514	509	554	606	623	728	884	990	997

The color legend of the graph is shown in the table.

Figure 1 – MSs certifications dynamics

The fixed effect panel regression approach was used in this research since it is better suited compared to the random effects approach, according to the Hausman test ($\chi^2(25)$ = 157,18; p=0.000). Three models were estimated, Model 1 includes only control variables, Model 2 focuses on the direct effect of the Certifications plus the control variables, and Model 3 also includes the interaction term between Certifications and Slack Resources. The results of the fixed effects panel regressions, which were estimated through OLS, are shown in Table 1.

Table 1 – Fixed effects OLS panel regressions

	Model 1	Model 2	Model 3
$Certifications_{t-1}$			
ISO9001		0.005	0.001
		(0.041)	(0.052)
ISO14001		**0.211*** **	**0.363*** **
		(0.029)	(0.040)
OHSAS18001		**0.084***	0.056
		(0.035)	(0.045)
ISO9001+ISO14001		**0.226*** **	**0.140** **
		(0.033)	(0.044)
ISO9001+OHSAS18001		-0.036	-0.158
		(0.057)	(0.094)
ISO14001+OHSAS18001		**0.252*** **	**0.179*** **
		(0.033)	(0.040)
Triple		**0.237*** **	**0.180*** **
		(0.032)	(0.042)
$Certifications_{t-1}$*$Slack_{t-1}$			
ISO9001			0.004
			(0.017)
ISO14001			**-0.089*** **
			(0.015)
OHSAS18001			0.016
			(0.016)
ISO9001+ISO14001			**0.050** **
			(0.016)
ISO9001+OHSAS18001			0.073
			(0.043)
ISO14001+OHSAS18001			**0.044*** **
			(0.013)
Triple			**0.036***
			(0.016)
$Slack_{t-1}$	-0.002	-0.002	-0.005
	(0.003)	(0.003)	(0.003)
$Stakeholders_{t-1}$	**0.002*** **	**0.001*** **	**0.001*** **
	(0.000)	(0.000)	(0.000)
$Env\_R\&D_{t-1}$	**0.098** **	**0.094** **	**0.099** **
	(0.031)	(0.031)	(0.031)
$Product\_Responsibility_{t-1}$	**0.002*** **	**0.002*** **	**0.002*** **
	(0.000)	(0.000)	(0.000)
Size	**0.081*** **	**0.074*** **	**0.078*** **
	(0.016)	(0.016)	(0.016)
Year dummies	Yes	Yes	Yes
Observations	22,179	22,179	22,179
R-squared	0.178	0.182	0.186
Number of id	2,859	2,859	2,859

Robust Standard errors in parentheses. *** p<0.001, ** p<0.01, * p<0.05

From Table 1, it can be observed that the direct effect of the ISO 14001 certification consistently shows a positive effect on EPI, regardless of its combination with other MSs. More specifically, the ISO 14001 single certification, as well as its combination with ISO 9001 and/or with OHSAS 18001 significantly improves EPI.

Regarding the moderating effect of slack resources, results are not so straightforward as in the direct effects. It can be observed that it negatively moderates the effect of ISO 14001 when adopted as a single certification. Nonetheless, the moderating effect is positive when the ISO 14001 is combined with the ISO 9001 or the OHSAS 18001 certification in a double certification scheme, or when combined with both the ISO 9001 and the OHSAS 18001 certifications (i.e., triple certifications).

5. DISCUSSION AND CONCLUSION

The aim of this paper is to analyze the impact of multiple management systems on eco-product innovation (EPI), as well as the moderating effect of Slack Resources on this relationship. According to the analysis done, three Management Systems (MSs), namely, ISO 14001, ISO 9001 and OHSAS 18001 have been studied.

The results show that EPI benefits can be obtained through the adoption of MSs being implemented alone or in combination with others. More specifically, ISO 14001 is found the main MS fostering EPI even when it is implemented in combination with ISO 9001 and OHSAS 18001. These results are in line with Hojnik and Ruzzier (2016) who also found ISO 14001 as the main driver of companies seeking to eco-innovate (see also Al-Shami and Rashid, 2022; Wang et al., 2022). The lack of effects of the ISO 9001 certification has also been reported by previous research, which contradicts the results reported in Cuerva *et al.* (2014).

When companies have a double certification, considering ISO 14001 and ISO 9001, as well as ISO 14001 and OHSAS 18001, the impact on EPI is also positive. This is in line with, for example, García-Quevedo et al. (2020), who also found a positive impact on the ISO 14001 and ISO 9001 combination.

The triple combination, i.e., ISO 14001, ISO 9001 and OHSAS 18001, also leads to EPI. These results are also in line with Bernardo (2014) and Hernandez-Vivanco et al. (2018), who found that when companies implement multiple MSs, they can achieve higher levels of innovation management and sustainable-product innovation respectively, mainly because of the compatibilities between standards that allow firms to manage them as a single MS. According to these results, H1a and H1b are confirmed. Therefore, the ISO 14001 acts as the main driver towards EPI, even when combined with the ISO 9001 or/and the OHSAS 18001 certifications.

Regarding the moderating effect of slack resources, H2a is confirmed as the ISO 14001 in combination with ISO 9001 and/or OHSAS 18001 (double or triple certification structures) lead to EPI in firms holding larger slack resources. This might be related to the reduction of perceived risk in these projects resulting from the engagement of customers (ISO 9001) and employees (OHSAS 18001), besides the environmental view provided by the ISO 14001 certification (Lo *et al.*, 2014; Naveh and Marcus, 2007; Waddock and Graves, 1997).

Finally, there is no effect of slack resources in firms holding only the ISO 9001 or the OHSAS 18001 certifications, in line with H2b. However, the negative effect of slack resources on EPI in firms holding the ISO 14001 single certification was not expected and more challenging to interpret. According to the existing literature on this topic, the result might be related to two main factors. Firstly, the ISO 14001 when adopted alone can be interpreted as a symbolic response to regulatory pressures. In these cases, firms would not give fundamental responses to the normative pressures exerted by stakeholders that are more knowledgeable on environmental issues, leading thus to a negative effect of slack resources on EPI (Berrone *et al.*, 2013). Another explanation might be related to the exploration and exploitation capacity of firms holding different levels of slack. According to Voss *et al.* (2018), slack resources are negatively associated to product exploitation. Therefore, results suggest that firms holding only the ISO 14001 would rather prefer investing on incremental (exploitation) rather than breakthrough EPI (exploration) as resources become scarce. According to this discussion, H2b is partially supported.

All in all, the main contribution of this paper is to analyze different possible combinations of MSs implementations within organizations, also considering the triple certification, and their impact on eco-product innovation, as well as the role of slack resources in moderating this relationship. It could be stated, that having the ISO 14001 leads to eco-product innovation, getting better results when combined with other quality and occupational health & safety MSs.

The main managerial implications of this work are based on the importance of implementing several MSs to achieve higher levels of eco-innovation. Therefore, organizations seeking to implement or improve eco-innovation can use MSs as a driver for it. In this case, having only the ISO 14001 helps, but the highest benefits of these MSs referred to eco-innovation comes from multiple MSs implemented, especially for firms with larger slack resources. For research, these results reinforce enrich the importance of MSs to achieve more efficient and sustainable companies, and the need to continue investigating them as tools for competitive advantage, bearing in mind the role of deploying the limited existing resources that firms hold.

The main limitation of this paper is the definition of variables, as it is done indirectly using an existing database. For this reason, factors such as the maturity and integration of MSs, as well as the motivations to adopt these practices could not be assessed. Moreover, including more practices that could be related to these MSs could improve the sample and the impact found. Future research will focus on overcoming these limitations.

REFERENCES

Al-Shami, S. and Rashid, N. (2022), "A holistic model of dynamic capabilities and environment management system towards eco-product innovation and sustainability in automobile firms", *Journal of Business & Industrial Marketing*, Vol. 37 No. 2, pp. 402–416.

Álvarez Gil, M.., Burgos Jiménez, J. and Céspedes Lorente, J.. (2001), "An analysis of environmental management, organizational context and performance of Spanish hotels", *Omega*, Vol. 29 No. 6, pp. 457–471.

Arora, P. and Dharwadkar, R. (2011), "Corporate Governance and Corporate Social Responsibility (CSR): The Moderating Roles of Attainment Discrepancy and Organization Slack", *Corporate Governance: An International Review*, Vol. 19 No. 2, pp. 136–152.

Bernardo, M. (2014), "Integration of management systems as an innovation: a proposal for a new model", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 82, pp. 132–142.

Bernardo, M., Simon, A., Tarí, J.J. and Molina-Azorín, J.F. (2015), "Benefits of management systems integration: a literature review", *Journal of Cleaner Production*, Vol. 94, pp. 260–267.

Berrone, P., Fosfuri, A., Gelabert, L. and Gomez-Mejia, L.R. (2013), "Necessity as the mother of 'green' inventions: Institutional pressures and environmental innovations", *Strategic Management Journal*, Vol. 34 No. 8, pp. 891–909.

Bourgeois, L.J. (1981), "On the Measurement of Organizational Slack", *Academy of Management Review*, Vol. 6 No. 1, pp. 29–39.

Carrillo-Hermosilla, J., Del Río, P. and Könnölä, T. (2010), "Diversity of eco-innovations: Reflections from selected case studies", *Journal of Cleaner Production*, Vol. 18 No. 10–11, pp. 1073–1083.

Cuerva, M.C., Triguero-Cano, Á. and Córcoles, D. (2014), "Drivers of green and non-green innovation: Empirical evidence in Low-Tech SMEs", *Journal of Cleaner Production*, Elsevier Ltd, Vol. 68, pp. 104–113.

Daddi, T., Heras-Saizarbitoria, I., Marrucci, L., Rizzi, F. and Testa, F. (2021), "The effects of green supply chain management capability on the internalisation of environmental management systems and organisation performance", *Corporate Social Responsibility and Environmental*

Management, Vol. 28 No. 4, pp. 1241–1253.

Daily, B.F. and Huang, S. (2001), "Achieving sustainability through attention to human resource factors in environmental management", *International Journal of Operations & Production Management*, Vol. 21 No. 12, pp. 1539–1552.

EIO (Eco-Innovation Observatory). (2010), "Methodological report", *Eco-Innovation Observatory*, Funded by the European Commission, DG, Environment, Brussels.

Fernando, Y., Chiappetta Jabbour, C.J. and Wah, W.-X. (2019), "Pursuing green growth in technology firms through the connections between environmental innovation and sustainable business performance: Does service capability matter?", *Resources, Conservation and Recycling*, Elsevier, Vol. 141 No. September 2018, pp. 8–20.

García-Quevedo, J., Kesidou, E. and Martínez-Ros, E. (2020), "Driving sectoral sustainability via the diffusion of organizational eco-innovations", *Business Strategy and the Environment*, Vol. 29 No. 3, pp. 1437–1447.

Heras-Saizarbitoria, I. and Boiral, O. (2013), "ISO 9001 and ISO 14001: Towards a Research Agenda on Management System Standards*", *International Journal of Management Reviews*, Vol. 15 No. 1, pp. 47–65.

Hernandez-Vivanco, A., Bernardo, M. and Cruz-Cázares, C. (2016), "Relating open innovation, innovation and management systems integration", *Industrial Management & Data Systems*, Vol. 116 No. 8, pp. 1540–1556.

Hernandez-Vivanco, A., Bernardo, M. and Cruz-Cázares, C. (2018), "Sustainable innovation through management systems integration", *Journal of Cleaner Production*, Vol. 196, pp. 1176–1187.

Hernandez-Vivanco, A., Domingues, P., Sampaio, P., Bernardo, M. and Cruz-Cázares, C. (2019), "Do multiple certifications leverage firm performance? A dynamic approach", *International Journal of Production Economics*, Vol. 218, pp. 386–399.

Hofer, C., Cantor, D.E. and Dai, J. (2012), "The competitive determinants of a firm's environmental management activities: Evidence from US manufacturing industries", *Journal of Operations Management*, Vol. 30 No. 1–2, pp. 69–84.

Hojnik, J. and Ruzzier, M. (2016), "What drives eco-innovation? A review of an emerging literature", *Environmental Innovation and Societal Transitions*, Elsevier B.V., Vol. 19, pp. 31–41.

Horbach, J., Rammer, C. and Rennings, K. (2012), "Determinants of eco-innovations by type of environmental impact - The role of regulatory push/pull, technology push and market pull", *Ecological Economics*, Elsevier B.V., Vol. 78, pp. 112–122.

ISO. (2021), *The ISO Survey*, International Organization for Standardization, Geneva, Switzerland, available at: http://www.iso.org/iso/iso-survey (accessed 28 April 2021).

Kemp, R. and Pearson, P. (2007), "Final report MEI project about measuring eco-innovation", *UM Merit, Maastricht*.

Kesidou, E. and Demirel, P. (2012), "On the drivers of eco-innovations: Empirical evidence from the UK", *Research Policy*, Elsevier B.V., Vol. 41 No. 5, pp. 862–870.

Lo, C.K.Y., Pagell, M., Fan, D., Wiengarten, F. and Yeung, A.C.L. (2014), "OHSAS 18001 certification and operating performance: The role of complexity and coupling", *Journal of Operations Management*, Elsevier B.V., Vol. 32 No. 5, pp. 268–280.

Montobbio, F. and Solito, I. (2018), "Does the Eco-Management and Audit Scheme Foster Innovation in European Firms?", *Business Strategy and the Environment*, Vol. 27 No. 1, pp. 82–99.

Naveh, E. and Marcus, A. (2007), "Financial performance, ISO 9000 standard and safe driving practices effects on accident rate in the U.S. motor carrier industry", *Accident Analysis and Prevention*, Vol. 39 No. 4, pp. 731–742.

Nohria, N. and Gulati, R. (1996), "Is Slack Good or Bad for Innovation?", *Academy of Management Journal*, Vol. 39 No. 5, pp. 1245–1264.

Oduro, S., Maccario, G. and De Nisco, A. (2021), "Green innovation: a multidomain systematic review", *European Journal of Innovation Management*, Vol. 25 No. 2, pp. 567–591.

Papagiannakis, G., Voudouris, I., Lioukas, S. and Kassinis, G. (2019), "Environmental management systems and environmental product innovation: The role of stakeholder engagement", *Business Strategy and the Environment*, Vol. 28 No. 6, pp. 939–950.

Ramus, C.A. (2002), "Encouraging innovative environmental actions: what companies and managers must do", *Journal of World Business*, Vol. 37 No. 2, pp. 151–164.

Rennings, K. and Rammer, C. (2011), "The Impact of Regulation-Driven Environmental Innovation on Innovation Success and Firm Performance", *Industry & Innovation*, Routledge, Vol. 18 No. 3, pp. 255–283.

Tan, J. and Peng, M.W. (2003), "Organizational slack and firm performance during economic transitions: two studies from an emerging economy", *Strategic Management Journal*, Vol. 24 No. 13, pp. 1249–1263.

Testa, M. and D'Amato, A. (2017), "Corporate environmental responsibility and financial performance: does bidirectional causality work? Empirical evidence from the manufacturing industry", *Social Responsibility Journal*, Vol. 13 No. 2, pp. 221–234.

Triguero, A., Moreno-Mondéjar, L. and Davia, M.A. (2016), "Leaders and Laggards in Environmental Innovation: An Empirical Analysis of SMEs in Europe", *Business Strategy and the Environment*, Vol. 25 No. 1, pp. 28–39.

Voss, G.B., Sirdeshmukh, D. and Voss, Z.G. (2008), "The Effects of Slack Resources and Environmentalthreat on Product Exploration and Exploitation", *Academy of Management Journal*, Vol. 51 No. 1, pp. 147–164.

Waddock, S.A. and Graves, S.B. (1997), "The Corporate Social Performance-Financial Performance link", *Strategic Management Journal*, Vol. 18 No. 4, pp. 303–319.

Wagner, M. (2008), "Empirical influence of environmental management on innovation: Evidence from Europe", *Ecological Economics*, Vol. 66 No. 2–3, pp. 392–402.

Wagner, M., Phu, N. Van, Azomahou, T. and Wehrmeyer, W. (2002), "The relationship between the environmental and economic performance of firms: an empirical analysis of the European paper industry", *Corporate Social Responsibility and Environmental Management*, Vol. 146 No. 9, pp. 133–146.

Wang, H., Masi, D., Dhamotharan, L., Day, S., Kumar, A., Li, T. and Singh, G. (2022), "Unconventional path dependence: How adopting product take-back and recycling systems contributes to future eco-innovations", *Journal of Business Research*, Elsevier Inc., Vol. 142 No. December 2021, pp. 707–717.

The perception of the impact of certification on organisational culture relative to the environment and occupational health and safety

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ABSTRACT

The uncertainty of the days and the existing challenges urge us to know the reality of the industry. The recent awareness of environmental changes and the concern for health and safety at workforce organisations focus on meeting the applicable legal requirements. These requirements mitigate humankind's harmful effects on the environment and its quality of life. The Management Systems and, in particular, Environment and Occupational Health and Safety are tools that allow organisations to counteract these harmful effects and reduce their impacts to become more competitive.

However, this requires the involvement of the entire organisation, intending to create ethical, consensual and widely disseminated codes of conduct that become part of the company's organisational culture.

Purpose - This paper aims to report the first part of a research project to obtain a portrait of industrial companies with one or more ISO certifications from the district of Aveiro relating to Environment and Occupational Health and Safety (OHS).

Design/methodology/approach – This field study implied a survey using a primary database (2020) of the Portuguese Institute of Accreditation (IPAC) with all the Aveiro's certified companies by at least one ISO management system (ISO9001 – Quality; ISO14001- Environmental; ISO45001- Occupational Health and Safety).

Findings - From an initial total of about 500 certified companies, 101organisations responded to the survey, constituting about 20% adhesion. Organisations, especially certified ones, should have an encouraging culture of openness to the scientific community to fieldwork. Several questions were addressed that allowed for a perception of organisations' policies, strategies, and measures in environmental and social sustainability and occupational health and safety as essential vectors in improving organisational performance.

Practical implications - Most organisations have external health and safety services that may help explain the relatively low adhesion. The vast majority do not follow or implement any health and safety at work referential standard. Nevertheless, they find it essential to guarantee better health and safety conditions, legal requirements, and decreased sinistrality. Despite near-miss reporting being a proactive and fundamental indicator to help improve work conditions, most companies referred to not doing it. Concerning the environment, about 40% of the organisations are certified by the ISO 14001:2015 standard. About 70% of the respondents allege external motivations for implementing environmental practices, namely legal requirements and market demands. The energy area is the one that deserves greater attention from organisations. About 79% have objectives to improve energy efficiency.

Value- This study contributes to the knowledge of the organisational culture in the environment and OHS of the Portuguese industry certified with one or more management systems.

Keywords: Environment; Occupational Health and Safety; Certification; Management systems; Organisational culture.

Paper type: Research paper

INTRODUCTION

Organisational culture is defined as a set of shared assumptions and values and expected behaviours and symbols, which guides the decisions of its members by establishing and reinforcing expectations about what is valued and how things should be done. Over time, an organisation builds its own culture, providing a sense of identity to its members about 'who we are' and 'what we do'. The organisation's culture is simultaneously reinforced and reshaped through the daily practices of its members (Bertels et al., 2010). Company leaders' vision influences the emotional and cultural organisation. The values, commitments and aspirations they want to achieve in the strategic business are shared with their members. Thus, their employees focus their attention on the essential issues using their interpersonal skills (Egri and Herman, 2000). Workers may also use their communication skills to generate positive relations with stakeholders (Azzone *et al.*, 1997). Organisational culture is a product of the simultaneous contact between employees and managers(Klammer, Grisold and Gueldenberg, 2019; Naveed *et al.*, 2022).

External forces can often drive the motivation for sustainable change, and sometimes the benefits may not appear to increase value directly. In cases where change is internally motivated, change may be initiated because one or more organisation members consider it to be 'the right thing to do'.

Research on organisational culture should assess what codes of conduct characterise an organisation that, when widely shared and maintained, shape its members' attitudes and behaviours(Chatman and O'Reilly, 2016). These codes should be analysed in three dimensions: the content of what is essential, such as teamwork or leadership example; the consensus on their application and maintenance and the importance that these codes play in the organisation that leads its members to sanction those who do not follow them.

There is a vast range of literature on organisational change from a strategic perspective and on specific types of cultural change, such as total quality management, which involves the culture of compliance, health and safety culture, and environmental culture.

Thus this study aimed to gauge the perception of organisational culture through human resource management and top management involvement in driving environmental and occupational health and safety performance. This work is part of a project to characterise industrial companies with one or more ISO certifications in the district of Aveiro related to the Environment and Occupational Health and Safety (OHS).

LITERATURE REVIEW

Organisational culture and safety

Occupational health and safety and work conditions are becoming essential aspects for evaluating organisations, with direct influences on productivity, effectiveness, and quality of work (Sujová and Cierna, 2018). Measuring characteristics of the safety culture is part of measuring OH&S performance. Many activities that support a positive safety culture need to be measured (Arezes and Sérgio Miguel, 2003). According to ILO statistics, every 15 seconds, a worker dies from an accident at work or a work-related illness. The ILO understands that a strong safety culture is the only effective way to deal with new and old risks(ILO, 2022a).

Culture is to society what memory is to individuals. One of the most straightforward definition is: "The way that we do things around here" (IAEA, 2002). "The culture of society encompasses both the intangible aspects (beliefs, ideas, values) and the tangible aspects that represent these contents (objects, symbols, technology) "(Giddens, 2001).

After the Chernobyl Nuclear Disaster in 1986, the International Atomic Energy Agency (IAEA) introduced a new concept, "Safety culture". Though this concept is crucial for high-risk industries (Çiftçioğlu et al., 2021), it did not gain any significant acceptance until the early 1990s and initially in the nuclear sector (Cox *et al.*, 1998). Nevertheless, every organisation has a safety culture that may affect safety (Hopkins, 1999; Nordlöf *et al.*, 2015). Unlike culture, there is no commonly accepted definition of safety culture (Strauch, 2015), but safety culture is deeply related to organisational culture (Arezes and Sérgio Miguel, 2003). Several authors and official institutions endeavour to provide different perspectives on this concept. Tharaldsen et al.(2008) stated that an organisation's safety culture is the collective ability to produce organisational and inter-organisational work practices that protect individual welfare and the environment. Safety culture is one component of organisational culture. It refers to "deeply held but often unspoken safety-related beliefs, attitudes, and values that interact with an organisation's systems, practices, people, and leadership to establish norms about how things are done in the organisation." (Goldenhar *et al.*, 2015). Hopkins (2006) refers that safety culture can be studied using three main methodology directions. One of them is perception surveys (questionnaires).

Certified companies have better rates for OHS practices than non-certified companies (Ghahramani, 2016). The new ISO 45001 Occupational Health and Safety Management system requires organisations to develop and promote a positive health and safety culture (BSI, no date). The ISO 45001 adoption is easier if the organisation has an existing ISO Management System (such as ISO 9001 or ISO 14001) because some common processes will be in place (Neag et al., 2019). Nevertheless, the standard cannot guarantee the fulfilment of its requirements (Ghahramani, 2016).

Accordingly, with ISO45001:2018, among the main reasons for OHS certification should be included: continual improvement of OHS performance; fulfilment of legal requirements and other; OHS objectives achievement (ISO, 2018).

The traditional safety performance indicators (reactive indicators such as the accidents statistics indices) seem limited (Arezes and Sérgio Miguel, 2003). Occupational health and safety country policies lead to proactive practices to prevent accidents at work, occupational diseases and possible undesirable situations (Mutlu and Altuntas, 2019). Proactive risk management strategies are replacing reactive methods based on analysis of accidents in the past (Rasmussen and Svedung, 2000). Proactive indicators are indicators "prior to an accident" (Rasmussen and Svedung, 2000; Körvers and Sonnemans, 2008). Cox et al. (1998) mention that the quality of safety training is considered a key factor for a strong safety culture. A near-miss (NM) is a proactive safety indicator (Körvers and

Sonnemans, 2008) and can be viewed as showing the vulnerability of a system. But, experiencing a near-miss can also reinforce the system's resiliency. It can indicate that, despite all the errors that led to the near-miss, the system was still protected against the hazard. Thus, to maintain a robust process safety culture, near-miss events should be regarded as an opportunity to reinforce a sense of vulnerability for all employees (Dee et al., 2013). Van der Schaaf and Kanse(2004) show that workers do not report their self-made errors, not due to being afraid/ashamed, but because they believed that reporting: would have no remaining consequences or it was not applicable; there was no learning withdrawn; workers were able to recover from self-made errors and other. There was evidence of a safety culture where workers felt free to report self-made mistakes and were able to recover from one's errors. Though Van der Schaaf and Kanse's study was "limited in time and resources", the leadership could understand that it is essential to believe and show interest in the NMS and use its results to improve corrective actions, communicating it to the whole organisation. Managers should introduce and foster a culture that permits employees to make mistakes and errors(Klammer, Grisold and Gueldenberg, 2019). Thus, they will feel confident reporting near-misses.

Bridges (2000) also refers that among the reasons for workers not reporting are the lack of management commitment and the lack of follow-through once a near-miss is reported. Zhou et al.(2019) mention, as well, that the company culture constitutes a possible obstacle to implementing an NMS. Reporting NM requires a change in the company's culture as workers must understand they are the ultimate risk managers (Kleindorfer *et al.*, 2012). Thus, safety culture is worth being considered and measured to realise employees' position and understanding of the enterprise's safety culture and make the organisation have a basis for improving it. Therefore, the company will discover its positive and negative aspects and determine the direction and benchmark for further improvement (Jiang *et al.*, 2020). Safety management is needed to motivate people to prevent injuries. Nevertheless, this activity is not sufficient to achieve a total safety culture. Thus, safety managers must become safety leaders and build personal responsibility rather than hold people accountable (Geller, 2000).

The World Day for Safety and Health at Work 2022 focuses on enhancing social dialogue towards a culture of safety and health, which confirms the importance of this theme (ILO, 2022b).

Organisational culture and environmental management

How companies approach environmental management can be grouped into two categories: control and prevention. The environmental performance achieved by both types of approaches is different. Ilinitch et al. (1998) show how environmental performance is multidimensional. They identify four conceptual dimensions of environmental performance: (1) organisational systems - organisational processes, including environmental audit programmes, environmental mission statements, etc.; (2) stakeholder relations - the interaction between the firm and its stakeholders; (3) regulatory compliance - the degree to which firms comply with legislation; and (4) environmental impact or environmental efficiency - negative economic and environmental externalities generated in firms.

Therefore, a differentiated approach to environmental problems will be needed, especially concerning their integration into business strategy (Cordano and Frieze, 2000). Azzone et al. (1997) and Azzone and Noci (1998) specify it for different types of business strategies.

The environmental management approach improves their environmental performance only concerning compliance with legislation through the reactive control strategy. Waste and emissions are prevented from negatively affecting the environment through specialised pollution abatement technologies, which are generally costly and unproductive. These actions are not value-generating. Thus they constitute a constraint for the company. Their influence on competitiveness is negative, reducing its capacity for innovation (Porter and Van Der Linde, 1995). As regulatory instruments start to appear and society and consumers become more demanding concerning the environmental actions of companies, control approaches thus prove to be insufficient.

From a company's internal perspective, environmental demands requiring preventive approaches in its environmental management should not be seen as unfavourable. They generate broader competitive advantages allowing the company to obtain extraordinary benefits (Russo and Fouts, 1997; Handfield *et al.*, 2001). Improving environmental performance through preventive actions requires a different approach to environmental issues, particularly concerning their integration into the company's business strategy (Azzone *et al.*, 1997). Adherence to Environmental Instruments (IA) has been decisive for the performance of organisations seeking to minimise their environmental impacts, adopting a set of sustainable practices that enable them to reduce the risks and costs associated with their activities while complying with the requirements to which laws bind them.

In the offensive prevention strategy, the company raises its environmental standards, not contenting itself with mere compliance with local environmental legislation. Indeed, they adopt the principles of pollution prevention, reduce the use of environmental resources and compliance with the law through changes in its processes and products (but not fundamental changes), anticipating the competition, such as the selection of raw materials, changes in packaging and the establishment of industrial standards. Adherence to Environmental Instruments as ISO 14001:2015, Environmental management System or EMAS EU Eco-Management and Audit Scheme has been decisive for the performance of organisations seeking to minimise their environmental impacts. Thus, they adopt sustainable practices that enable them to reduce the risks and costs associated with their activities while complying with the requirements to which laws bind them. ISO 14001:2015 establishes requirements for three components of environmental performance to be inscribed in the policy: the commitment to comply with applicable legislation and regulations, continuous improvement and pollution prevention (Pires, 2016).

In the innovation strategy, companies anticipate future environmental problems by attacking them at their source, strengthening their market position. Environmental excellence becomes a sine qua non condition for the success of companies, feeling the need for integration between environmental and commercial aspects.

The move towards preventive environmental approaches requires significant changes in company organisation. It requires companies to rely increasingly on organisational involvement and learning resources, thus underlining the importance of organisational culture (Russo and Fouts, 1997; Boiral, 2002). Effective implementation of an advanced environmental approach requires a culture based on ecological values that involve a high degree of awareness among employees (Del Brio, Junquera and Ordiz, 2008). Dealing with environmental issues also requires top management to address leadership concerns. Portugal and Yukl (1994) analysed some transformational leadership behaviours. Articulating a recurring alternative view on environmental issues, changing perceptions on environmental issues, and expectations in symbolic actions to show personal commitment to the issue are essential aspects of environmental leadership.

Thus, organisational culture or legitimising the issue as an integral part of corporate identity is one of the critical factors in achieving better environmental performance in companies by raising employee awareness of these issues (Russo and Fouts, 1997; Azzone and Noci, 1998; Egri and Herman, 2000; Handfield *et al.*, 2001).

RESEARCH METHODOLOGY

There has been a significant increase in the number of Portuguese companies certified in Quality, Environment and Health and Safety in recent years. However, there is no perception of the impact of these certifications on the safety and environmental culture. Thus, some dimensions intrinsically connected to safety culture assessment and environmental culture are presented in this field study as some indicators are inherently related to it.

This study was carried out using a survey by questionnaire, characterised by posing questions to the company's representatives, allowing for subsequent quantitative treatment, and making it possible to carry out "correlation analyses".(Quivy and Campenhoudt, 1998) This tool allows researchers to gather a large amount of information at a low cost, regardless of the significant non-response usually associated with surveys.

Table 1 - Sections and topics of the questionnaire

Sections	**Main topics of the questionnaire**
Characterisation of the enterprise	Economic activity classification (CAE)
	No. of worker
Characterisation of the OHS area	OHS Services
	OHS certification and main reasons
	OHS indicators used
	Near-misses
Characterisation of the environmental area	Characterisation of the most significant environmental aspects and impacts
	Motivation towards sustainability practices of an environmental nature
	Environmental instruments implemented
	Environmental practices implemented

Data Collection Process

The questionnaire survey is organised into three sections, as evidenced in Table 1. Depending on the nature of the question and the data available, questions were asked of a quantitative nature, i.e. structured questions that specify a set of alternative responses and the response format.

The questionnaire was designed with: open-ended questions, multiple-choice questions where respondents opt for one of the alternatives or a certain allowed number of options, and dichotomous questions that present only two choices of answers: yes/no.

Sample and d Data Collection Technique

The survey applied in this study was developed in Microsoft Forms and sent to companies via email with the respective link. The Portuguese Accreditation Institute (IPAC) database(IPAC, 2022) was used to select the companies. The sample under study consists of 101 companies from approximately 500 organisations from the business fabric of Aveiro (approximately 20% of the population), with a minimum of 1 normative certification. The questionnaire survey was disseminated via email mainly to the companies' quality or integrated management systems responsible. In addition, emails were also sent to AIDA (Industrial Association of the District of Aveiro) to further disseminate the questionnaire survey to its members. All these means aimed to obtain the highest possible number of responses.

RESULTS AND DISCUSSION

Although certified companies tend to have better environmental and OHS practices than non-certified companies (Ghahramani, 2016), one would expect higher participation in this type of study. However, only around 20% of companies (101 companies) responded to the survey.

Another study (Morgado et al., 2019) conducted on a national scale for OHS issues only and ISO 45001 certified companies corroborates this figure with participation rates of around 20%. Concerning OHS, a possible explanation for this rate may be that only 25% of organisations have internal OHS services.

Concerning the size of the companies in this study, 87% of the companies are SMEs (Fig.1).

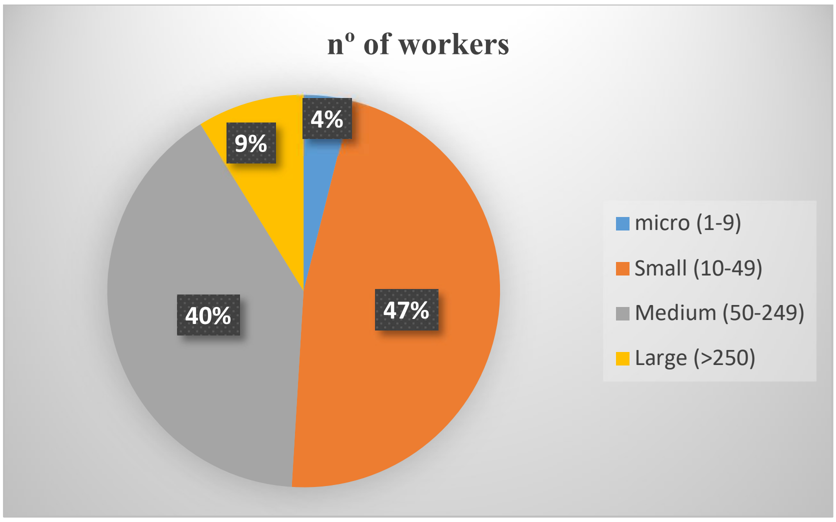

Fig.1 – Distribution by number of workers of the companies

The companies were mainly from the metalworking sector (Fig.2), which is characteristic of the region in study.

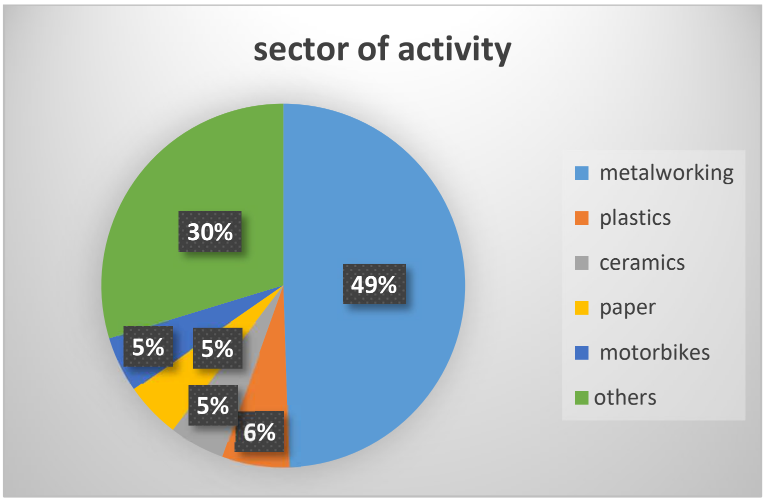

Fig.2 – Distribution of enterprises' activity classification

As already mentioned, all the companies in this study are certified with at least one normative reference. Of the companies that responded to this survey, 100% are certified in the Quality Management System (QMS) NP ISO 9001:2015, and 43% are also certified in the Environmental Management System (EMS) NP ISO 14001:2015 / Eco-Management and Audit Scheme (EMAS), and 12% are also certified in the Occupational Health and Safety Management Systems (OHSMS) ISO 45001:2018. A general reason for OHS certifications being low may be that only 9% of the companies in the survey are big companies, typically companies with higher resources than SMEs.

Characterisation of the OHS certification respondents

Regarding OHS certification, only 12% of the respondent companies were OHS certified by ISO 45001:2018. Some reasons for certification were presented in the questionnaire, and companies chose the ones that made them decide on an OHS certification (fig. 3).

Fig. 3 - Main reasons for OHS Certification

Indeed, accordingly to ISO 45001:2018 (ISO, 2018), among the main reasons for OHS certification are the fulfilment of legal requirements and other (referred by 57% of the respondent companies); achievements of OHS objectives that should include a decrease in accidents at work (referred by 56% of the respondent companies), among others. Nevertheless, some organisations still act reactively, looking for certification as a customer and a market requirement (referred by 20% of the respondent companies), as in Neag et al. (2019).

OHS performance indicators

Related to OHS performance indicators, 68% of the companies participating in this study identified OHS performance indicators that, according to ISO45001:2018, must be associated with each OHS objective and measured and monitored periodically (ISO, 2018; Morgado et al., 2019).

All companies identified reactive indicators, but only 47% identified proactive indicators. The most used proactive indicators are presented in figure 4.

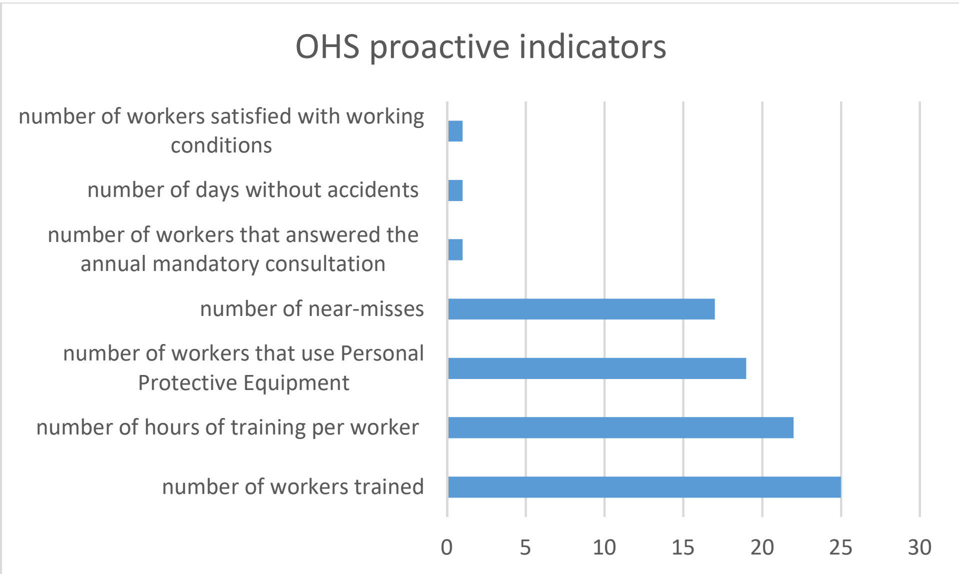

Fig. 4 - OHS proactive indicators used by respondent companies

Reactive indicators are used by all companies that fill the mandatory annual report known as the "Unique Report" demanded by the Portuguese Order nº 55/2010. Nevertheless, an occupational health and safety management system enable organisations to provide safe and healthy workplaces by preventing work-related injury and ill-health and proactively improving their OHS performance (ISO, 2018). Proactive practices should be carried out more and more to prevent accidents at work, occupational diseases, and possible undesirable situations (Mutlu and Altuntas, 2019). One of the most referred proactive indicators was related to the workers' training (number of workers trained and number of working hours) which is mandatory by the Portuguese Employment Code, Law nº 7/2009.

Near-misses

In this survey, 22% of the companies report near-misses.

Near-miss management is mandatory in the Major Accident Hazard (MAH) legislation (Gnoni *et al.*, 2013). Though other employers are not currently required to report near-miss data(OSHA, no date; Awolusi and Marks, 2015), the authors agree with the importance of managing efficiently near-miss events to improve risk prevention in a company. Near-miss Management Systems are considered proactive strategies to dynamically enhance occupational safety management (Gnoni *et al.*, 2013). Thus, it would be important that more companies use the number of near-misses as a proactive indicator.

Some reasons for reporting near-misses were presented in the questionnaire, and companies chose the ones that made them decide on this crucial procedure (Fig. 5).

Fig. 5 - Reasons pointed by respondent companies for reporting near-misses

Since near-misses and accidents share many common causes, learning from near-misses contributes to preventing accidents (Gnoni and Saleh, 2017), so a decrease in accidents at work should be one of the main reasons for reporting near-misses. After reporting near-misses, near-miss management foresees corrective actions to address, eliminate, or mitigate these anomalies (Gnoni and Saleh, 2017), improving work conditions.

Supervisors and top management awareness are critical points in anticipating hazard release and taking appropriate action (Mitropoulos et al., 2005). Leadership must believe and show interest in the near-miss management and use its results to improve corrective actions, communicating them to the whole organisation(Van Der Schaaf and Kanse, 2004). Thus, it is one of the main reasons for reporting near-misses.

All companies that report near-misses mentioned that the procedure proved to help improve their company's OHS conditions.

Near-miss management is fundamental. However, it does not entirely prevent accidents. Nevertheless, the most predictable ones can be avoided based on the actual conditions of the workplace. Thus, measuring its performance is a way to apply proactive strategies for preventing accidents (Andriulo and Gnoni, 2014).

Meanwhile, the vast majority of the respondent companies (88%) did not report near-misses. Some reasons for not reporting near-misses were presented in the questionnaire, and companies chose the ones that made them not follow this procedure (Fig. 6).

Fig. 6 - Reasons pointed by respondent companies for not reporting near-misses

Van der Schaaf and Kanse (2004) study shows that workers did not report near-misses, not due to being afraid/ashamed, but mainly due to not believing leadership would take action, the procedure would not be helpful. There was evidence of a safety culture where workers felt free to report self-made mistakes and were able to recover from one's errors. In this study, companies still found shame critical for workers not reporting near-misses.

Despite training being mandatory by law, as referred above, it still is referred to as one of the main causes for not reporting near-misses.

Though organisations must take action to avoid reprisals and promote a safe environment (ISO, 2018), this is still a cause in some organisations for workers not reporting near-misses.

Characterisation of the most significant environmental aspects and impacts

Regarding the most significant environmental aspect for the companies (fig. 7), it can be verified that the majority (70%) of the companies consider the consumption of natural resources (water, energy and raw materials consumption) as the most significant environmental aspect in them, followed by the production of solid waste with a weight of 19%, 7% greenhouse gas emissions and 3% production of liquid effluents. These results reflect the environmental aspects characteristic of the dominant economic sector (metalworking).

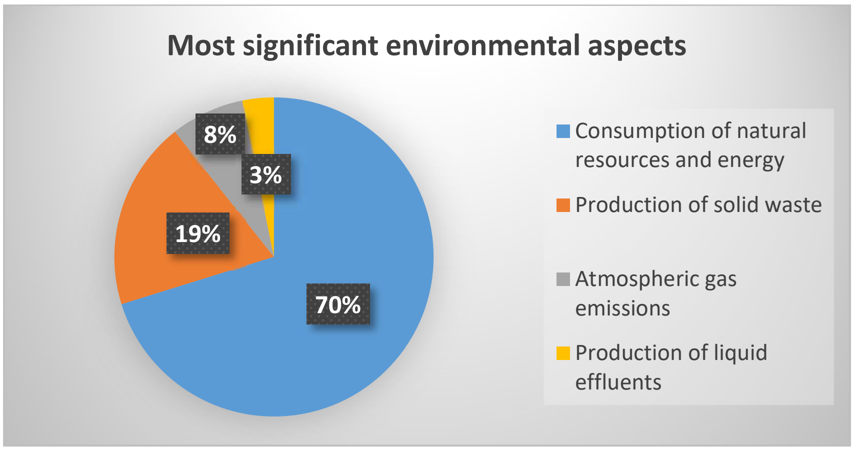

Fig.7 - Most significant environmental aspects for companies

Concerning the environmental impact the companies consider to be most significant in their activities (fig. 8), air pollution stands out with a relevance of 30%, soil contamination with a weight of 12%, water contamination at 8% and dilapidation of resources 7%. It is curious to note that about 13% (others) of the respondents do not know how to distinguish environmental aspects and their impacts, and 30% say they have no environmental impacts in their activities. According to Del Brio & al. (2008), the effective implementation of an advanced environmental approach requires a culture based on ecological values that involve a high degree of awareness on the part of employees. From the analysis of these two questions, a lack of knowledge in this area can be found.

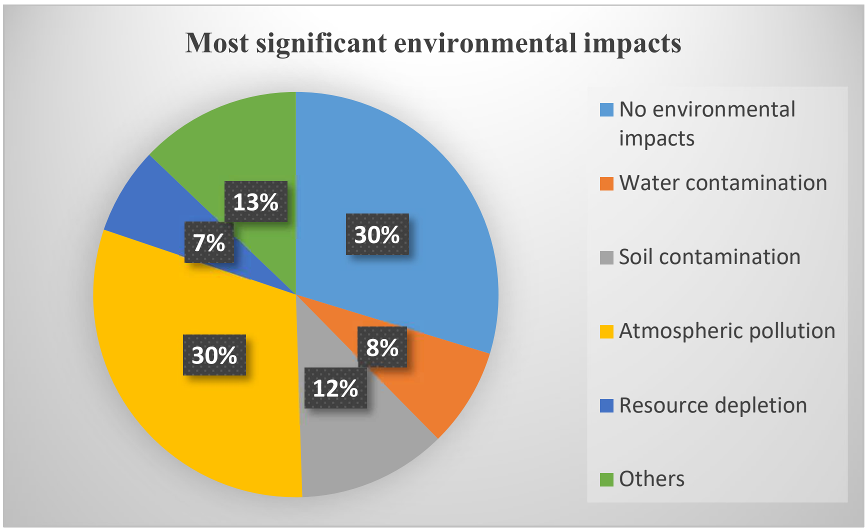

Fig.8 - Most significant environmental impacts for companies

Motivation for environmental sustainability practices

Concerning the motivation for the implementation of environmental practices (fig. 9), it can be seen that the majority (43%) of the companies consider that regulatory requirements have significant relevance to the implementation of environmental practices. It should also be noted that 35% of the respondents consider that the awareness of shareholders and managers is one of the main factors of internal motivation. In comparison, 22% reveal that the implementation of environmental practices comes from market requirements.

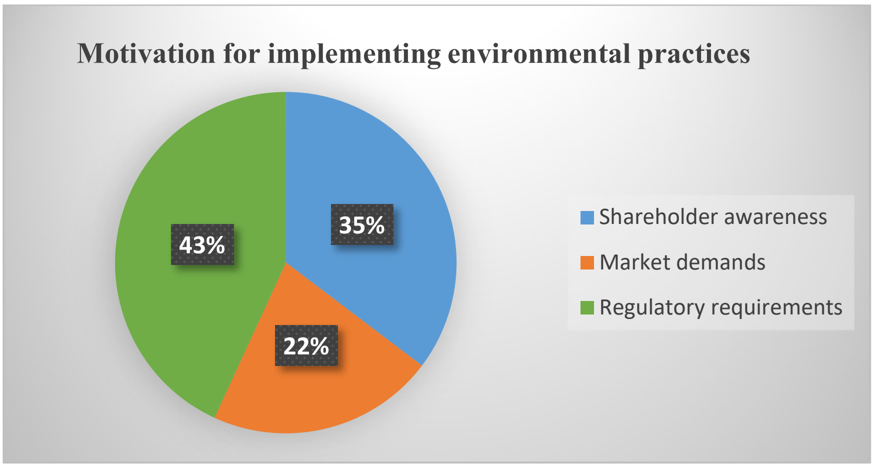

Fig.9 -Motivation for implementing environmental practices

It should be noted that companies with ISO 14001:2015 EMS certification accompany this trend.

Porter and Linde (1995) showed that environmental regulations conducted appropriately have the potential to cause innovations. Therefore, companies can reduce the total costs of a product and increase its value by allowing them to use inputs such as raw materials, energy, and labour more productively. Thus, environmental requirements that force companies to introduce preventive approaches in their environmental management should not be seen as unfavourable. They generate broader competitive advantages that allow the company to obtain extraordinary benefits (Russo and Fouts, 1997).

Thus, to the question asked about the "Importance of improving environmental sustainability in processes and products", 91% of the companies consider that improving environmental sustainability in processes and products is important. The remainder considers it "Not a priority for Management". In this way, it is possible to verify a strong corporate awareness for the improvement of environmental sustainability regarding their respective processes and products.

When questioned as to whether they know how they can improve the environmental sustainability of their processes, 77% of the companies assume that they have sufficient knowledge to implement the improvement, highlighting that the level of knowledge is present in a considerable part of Aveiro's daily business life.

The answers to this set of questions show a strong entrepreneurial awareness for the improvement of environmental sustainability in what concerns their respective processes and products.

The evolution towards preventive environmental approaches requires important changes in company organisation. It requires companies to rely more and more on organisational involvement and learning resources, thus highlighting the importance of organisational culture (Russo and Fouts, 1997; Boiral, 2002).

Implemented environmental instruments and strategies

Concerning environmental instruments, it was analysed whether the companies under study had some kind of strategy in the use of environmental practices and/or instruments. Environmental strategies represent how organisations mobilise internally and externally to create environmental tactical tools that can respond positively to the environmental impacts caused by their production processes (Barbosa and Candido, 2013). To this question, only 73% of the respondents stated that they have well-defined environmental strategies.

Regarding the environmental instruments currently certified, companies highlight NP EN ISO 14001:2015 (42%) as the most common, followed by 2% with EMAS certification, 2% with eco-labels and two companies from the paper and cork sector certified with the FSC (Forest Stewardship Council). This international standard has been identified as a tool of great importance in helping organisations to evolve from simple compliance with the legislation in force to a position of better productivity and greater competitive advantage (Martin-Tapia, Aragon-Correa and Senise-Barrio, 2008).

Implemented environmental practices

The following questions were analysed in more detail if the companies replaced products, materials and raw materials for new products, materials and recyclable raw materials and if they have environmental criteria in selecting their suppliers and in the acquisition of materials and raw materials. 46% of the respondents already adopt environmental concern criteria in selecting their suppliers and acquiring materials, and around 49% of the companies already use recycled materials. Since the sample under study is mainly from the metalworking sector, it is already common practice to recycle their waste (scrap) for incorporation into their products, especially in recent times with the scarcity of this type of raw material. The industry needs to go beyond the limits of a single organisation and get involved in collaborative networks. In these multiple networks, various stakeholders are working together to co-create value (Reypens, Lievens and Blazevic, 2016)

In terms of energy, 79% of the companies have their objectives well defined regarding improving their energy efficiency, the consequence of this input being one of the highest current costs for the operationalisation of the companies.

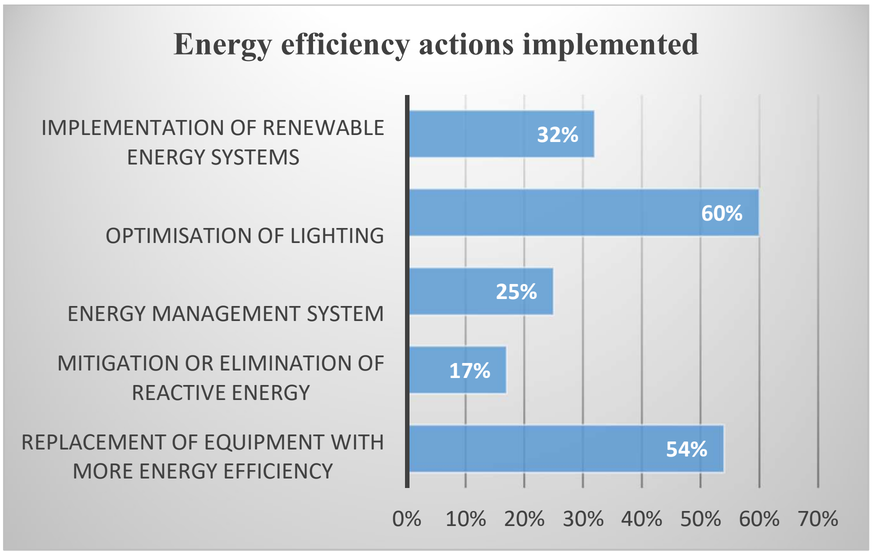

Fig.10- Energy efficiency actions implemented

Among the measures adopted in the improvement of their energy efficiency are actions such as (fig.10): optimisation of lighting (60%), equipment replacement by other more energy-efficient

(54%), the implementation of renewable energy systems with a preponderance of 32%, 25% of companies implementing an energy management system and 17% of companies investing in the mitigation or elimination of reactive energy.

ACKNOWLEDGEMENTS

Without the responses of the various companies to the survey, it would be impossible to disclose this study. It was also essential to this study the database of the IPAC (Portuguese Institute of Accreditation) of all Portuguese certified companies.

CONCLUSIONS

This study shows that despite organisations being certified, there is still a long and challenging road to improving organisational culture. The organisations still follow an offensive environmental strategy. Fundamental changes are incipient and driven by external forces. Leadership awareness and worker's training are essential issues. Workers will understand the importance of correct near-miss reporting and adhere voluntarily to it if they believe that management will take it seriously and will effectively improve safety at work. A culture that encourages workers to report near-misses must be considered a critical leadership goal.

Company leaders create a vision that influences the emotional and cultural organisation by sharing with their members the values, commitments and aspirations they want to achieve in the business, safety and environmental field to achieve sustainable development. An efficient organisational culture must involve all employees and allow them to notice the impact they generate in this gradual process. Sustainable companies are resilient organisations with strong cultures that strive to support a healthy environment and improve the lives of others while continuing to operate successfully over the long term.

Limitations: This field study could not comprise all the dimensions that characterise safety culture. Organisations are not motivated to reply to extensive questionnaires, and this was a study that comprehends both environmental and occupational health and safety issues. Companies under the survey were certified with at least one normative certification. Nevertheless, the vast majority did not have internal safety services. That may have limited both quantitative and qualitative aspects of the survey.

Research implications: This was an exploratory study. A broader survey with all the dimensions for assessing safety culture should be implemented. As most companies do not possess internal safety services, a personal contact rather than an email contact could guarantee better and more significant results, even if it may be challenging to implement. A more extensive questionnaire should be elaborated and sent to the companies detailing the characteristics of the certifications as the time of first certifications and others. This study should be carried out by sector.

REFERENCES

Andriulo, S. and Gnoni, M. G. (2014) 'Measuring the effectiveness of a near-miss management system: An application in an automotive firm supplier', *Reliability Engineering and System Safety*, 132, pp. 154–162. doi: 10.1016/j.ress.2014.07.022.

Arezes, P. M. and Sérgio Miguel, A. (2003) 'The role of safety culture in safety performance measurement', *Measuring Business Excellence*, 7(4), pp. 20–28. doi: 10.1108/13683040310509287.

Awolusi, I. and Marks, E. (2015) 'Near-miss reporting to enhance safety in the steel industry', *Iron and Steel Technology*, 12(10), pp. 62–68.

Azzone, G. *et al.* (1997) 'Defining operating environmental strategies: programmes and plans within Italian industries', *Environmental Management and Health*, 8(1), pp. 4–19. doi: 10.1108/09566169710159159.

Azzone, G. and Noci, G. (1998) 'Seeing ecology and "green" innovations as a source of change', *Journal of Organizational Change Management*, 11(2), pp. 94–111. doi: 10.1108/09534819810212106.

Barbosa, M. D. F. N. and Candido, A. G. (2013) ‘Práticas Ambientais e suas Relações com a Competitividade e a Sustentabilidade: um estudo de caso em empresa agroindustrial’, *Latin American Journal of Business Management*, 4, pp. 58–74.

Bertels, S., Papania, L. and Papania, D. (2010) 'Embedding sustainability in organisational culture. A systematic review of the body of knowledge', *Network for Business Sustainability*, pp. 1–74.

Boiral, O. (2002) 'Tacit knowledge and environmental management', *Long Range Planning*, 35, pp. 291–317.

Bridges, W. G. (2000) 'Get near misses reported - Process Industry Incidents: Investigation protocols, Case histories, Lessons learned', in, pp. 379–399.

Del Brio, J. Á., Junquera, B. and Ordiz, M. (2008) 'Human resources in advanced environmental approaches-a case analysis', *International Journal of Production Research*, 46(21), pp. 6029–6053.

doi: 10.1080/00207540701352094.

BSI (no date) *The new international way to manage occupational health & safety*.

Chatman, J. A. and O'Reilly, C. A. (2016) 'Paradigm lost: Reinvigorating the study of organisational culture', *Research in Organizational Behavior*, 36, pp. 199–224. doi: 10.1016/J.RIOB.2016.11.004.

Çiftçioğlu, G. A., Kadirgan, M. A. N. and Eşiyok, A. (2021) 'Determining the safety culture in a gun factory in Turkey: A fuzzy approach', *Journal of Intelligent & Fuzzy Sysytems*.

Cordano, M. and Frieze, H. I. (2000) 'Pollution Reduction U . S . Environmentl Managers : Applyinng Ajzen's Theory of Plannned Behaviour', *Acadamy of Management Journal*, 43(4), pp. 627–641.

Cox, S. *et al.* (1998) 'Safety Culture: The Prediction of Commitment to Safety in the Manufacturing Industry', *British Journal of Management*, 9(s1), pp. 3–11. doi: 10.1111/1467-8551.9.s1.2.

Dee, S. J., Cox, B. L. and Ogle, R. A. (2013) 'Using near misses to improve risk management decisions', *Process Safety Progress*, 32(4), pp. 322–327. doi: 10.1002/prs.11632.

Egri, C. P. and Herman, S. (2000) 'Leadership in the North American Environmental Sector':, *Academy of Management Executive*, 43(4), pp. 571–604.

Geller, E. S. (2000) '10 leadership qualities for a total safety culture', *Professional Safety*. Available at: http://campus.murraystate.edu/academic/faculty/dfender/OSH650/readings/Geller--10 Leadership Qualities for a Total Safety Culture.pdf (Accessed: 20 April 2021).

Ghahramani, A. (2016) 'Diagnosis of poor safety culture as a major shortcoming in OHSAS18001-certified companies', *Industrial Health*.

Giddens, A. (2001) *Sociology*. 4th edition. Polity Press.

Gnoni, M. *et al.* (2013) '"Lean occupational" safety: An application for a Near-miss Management System design', *Safety Science*, p. 12,13. doi: 10.1016/j.ssci.2012.09.012.

Gnoni, M. G. and Saleh, J. H. (2017) 'Near-miss management systems and observability-in-depth: Handling safety incidents and accident precursors in light of safety principles', *Safety Science*. Elsevier B.V., pp. 154–167. doi: 10.1016/j.ssci.2016.08.012.

Goldenhar, L. M. *et al.* (2015) 'Safety Culture and Safety Climate in Construction: Bridging Research and Practice'. Available at: https://onepetro.org/ASSPPDCE/proceedings-abstract/ASSE15/All-ASSE15/ASSE-15-603/78243 (Accessed: 30 March 2022).

Handfield, R. B. *et al.* (2001) 'Integrating environmental concerns into the design process: The gap between theory and practice', *IEEE Transactions on Engineering Management*, 48(2), pp. 189–208. doi: 10.1109/17.922478.

Hopkins, A. (1999) 'Counteracting the Cultural Causes of Disaster', *Journal of Contingencies and Crisis Management*, 7(3), pp. 141–149. doi: 10.1111/1468-5973.00107.

Hopkins, A. (2006) 'Studying organisational cultures and their effects on safety', *Safety Science*, 44(10), pp. 875–889. doi: 10.1016/j.ssci.2006.05.005.

IAEA (2002) *Safety culture in nuclear installations Guidance for use in the enhancement of safety culture*.

Ilinitch, A. Y., Soderstrom, N. S. and E. Thomas, T. (1998) 'Measuring corporate environmental performance', *Journal of Accounting and Public Policy*, 17(4–5), pp. 383–408. doi: 10.1016/S0278-4254(98)10012-1.

ILO (2022a) *Segurança e Saúde no Trabalho*. Available at: https://www.ilo.org/lisbon/temas/WCMS_650864/lang--pt/index.htm (Accessed: 4 May 2022).

ILO (2022b) *World Day for Safety and Health at Work 2022 (Safety and health at work)*. Available at: https://www.ilo.org/global/topics/safety-and-health-at-work/events-training/events-meetings/safeday2022/lang--en/index.htm (Accessed: 10 May 2022).

IPAC (2022) *Base de dados nacional de sistemas de gestão certificados*.

ISO (2018) *ISO Standard No. 45001:2018 -Occupational health and safety management systems — Requirements with guidance for use*.

Jiang, W. *et al.* (2020) 'Study on quantitative measurement result of safety culture', *Safety Science*, 128. doi: 10.1016/j.ssci.2020.104751.

Klammer, A., Grisold, T. and Gueldenberg, S. (2019) 'Introducing a "stop-doing" culture: How to free your organisation from rigidity', *Business Horizons*, 62(4), pp. 451–458. doi: 10.1016/J.BUSHOR.2019.03.002.

Kleindorfer, P. *et al.* (2012) 'Assessment of catastrophe risk and potential losses in industry', *Computers and Chemical Engineering*, 47, pp. 85–96. doi: 10.1016/j.compchemeng.2012.06.033.

Körvers, P. M. W. and Sonnemans, P. J. M. (2008) 'Accidents: A discrepancy between indicators and facts!', *Safety Science*, 46(7), pp. 1067–1077. doi: 10.1016/J.SSCI.2007.06.004.

Martin-Tapia, I., Aragon-Correa, J. A. and Senise-Barrio, M. E. (2008) 'Being green and export intensity of SMEs: The moderating influence of perceived uncertainty', *Ecological Economics*, 68(1–2), pp. 56–67. doi: 10.1016/j.ecolecon.2008.01.032.

Mitropoulos, P., Abdelhamid, T. S. and Howell, G. A. (2005) 'Systems Model of Construction Accident Causation', *Journal of Construction Engineering and Management*, 131(7), pp. 816–825.

doi: 10.1061/(ASCE)0733-9364(2005)131:7(816).

Morgado, L., Silva, F. J. G. and Fonseca, L. M. (2019) 'Mapping Occupational Health and Safety Management Systems in Portugal: outlook for ISO 45001:2018 adoption', *Procedia Manufacturing*, 38, pp. 755–764. doi: 10.1016/J.PROMFG.2020.01.103.

Mutlu, N. G. and Altuntas, S. (2019) 'Assessment of occupational risks In Turkish manufacturing systems with data-driven models', *Journal of Manufacturing Systems*, 53, pp. 169–182. doi: 10.1016/j.jmsy.2019.09.008.

Naveed, R. T. *et al.* (2022) 'Do organisations really evolve? The critical link between organisational culture and organisational innovation toward organisational effectiveness: Pivotal role of organisational resistance', *Journal of Innovation & Knowledge*, 7(2), p. 100178. doi: 10.1016/J.JIK.2022.100178.

Neag, P., Ivascu, L. and Draghici, A. (2019) 'A debate on issues regarding the new ISO 45001:2018 standard adoption', *MATEC*. doi: 10.1051/matecconf/202030500002.

Nordlöf, H. *et al.* (2015) 'Safety culture and reasons for risk-taking at a large steel-manufacturing company: Investigating the worker perspective', *Safety Science*, 73, pp. 126–135. doi: 10.1016/j.ssci.2014.11.020.

OSHA (no date) *OSHA Injury and Illness Recordkeeping and Reporting Requirements*. Available at: https://www.osha.gov/recordkeeping/ (Accessed: 30 March 2020).

Pires, A. (2016) *Sistemas de Gestão da Qualidade, Ambiente, Segurança, Responsabilidade Social, Indústria e Serviços*. 2nd edn.

Porter, M. E. and Van Der Linde, C. (1995) 'Toward a new conception of the environment-competitiveness relationship', *Journal of Economic Perspectives*, 9(4), pp. 97–118. doi: 10.1257/jep.9.4.97.

Portugal, E. and Yukl, G. (1994)' Perspectives on environmental leadership', in *Leadership Quart.*, pp. 5, 271–276.

Quivy, R. and Campenhoudt, L. C. (1998) *Manual de Investigação em Ciências Sociais*. 2ª edição. Edited by L. Gradiva -Publicações. Lisboa.

Rasmussen, J. and Svedung, I. (2000) *Proactive Risk Management in a Dynamic Society*. Edited by B. O. Sjuhäradsbygdens Tryckeri.

Reypens, C., Lievens, A. and Blazevic, V. (2016) 'Leveraging value in multi-stakeholder innovation networks: A process framework for value co-creation and capture', *Industrial Marketing Management*, 56, pp. 40–50. doi: 10.1016/j.indmarman.2016.03.005.

Russo, M. V. and Fouts, P. A. (1997) 'A Resource-Based Perspective On Corporate Environmental Performance And Profitability', *Academy of Management Journal*, 40(3), pp. 534–559. doi: 10.5465/257052.

Van Der Schaaf, T. and Kanse, L. (2004) 'Biases in incident reporting databases: An empirical study in the chemical process industry', *Safety Science*, 42(1), pp. 57–67. doi: 10.1016/S0925-7535(03)00023-7.

Strauch, B. (2015) 'Can we examine safety culture in accident investigations, or should we?', *Safety Science*, 77, pp. 102–111. doi: 10.1016/j.ssci.2015.03.020.

Sujová, E. and Cierna, H. (2018) 'Complex Evaluation of Safety Culture Determinants in Manufacturing Companies in Slovakia', 0, pp. 0–4.

Tharaldsen, J. E., Olsen, E. and Rundmo, T. (2008) 'A longitudinal study of safety climate on the Norwegian continental shelf', *Safety Science*, 46(3), pp. 427–439. doi: 10.1016/j.ssci.2007.05.006.

Zhou, Z. *et al.* (2019) 'Exploring the potential use of near-miss information to improve construction safety performance', *Sustainability (Switzerland)*, 11(5). doi: 10.3390/su11051264.

Assessing the use of pre-trained transformers to classify customer reviews

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ABSTRACT

Purpose: This paper aims to study the validity of using pre-trained transformers to extract customer sentiment from written reviews. Internet retailing and e-commerce have enabled users to post reviews expressing their opinions about products and services. Online customer reviews support not just new customers, who can use these prompt actionable pieces of information to decide on their purchase, but also business and research areas, who can use it to obtain the changing and emerging customer and market requirements, i.e., the voice of the customer. Although customer online reviews may be very subjective, the use of Machine Learning (ML) methods to extract relevant customer feedback is in order. Recently, transformers took Natural Language Processing (NLP) by storm breaking state-of-the-art benchmarks on every NLP task.

Design/methodology/approach: Five pre-trained transformer models (*Finbert, Bert-base, Finbert-tone, DistilRoberta, and Twitter-Roberta*) are applied to an Amazon database of automotive products for opinion mining/sentiment analysis of written reviews, which are then compared with the quantitative 5-star rating given by the consumer. Considering the 5-points Likert scale in the star rating, the comparison to each model prediction was done by mapping the stars given on the dataset into 3 classes, where the positive sentiment is equal to five and four stars, the neutral is equal to three stars, and the negative is equal to one and two stars. A 6th ensemble model was also developed to take in the predictions from the transformers and make a prediction. This model was added to investigate if a pipeline would perform better than a single transformer.

Findings: The results indicate that although transformers may be a useful tool to extract customer satisfaction from customer reviews, choosing an appropriate model is critical to obtaining reliable metrics. Among the tested models, the "*Twitter-Roberta*" presented the higher performance in predicting the correct customer sentiment within this paper. It was also found that adding an ensemble of transformers to make the final prediction improves performance. The ensemble model is the best one.

Practical implications: An automated sentiment assessment system can be useful to identify customer satisfaction from written text collected across the web and particularly on social media, or via the usual enterprise communication channels. This data can then be used in a multitude of practical scenarios, such as product review monitoring; market research; recommender systems; and pre-screening of customer communications (web forms, email). Using our methodology, the use of transformers becomes much more accessible since training a transformer from scratch is beyond reach for most organizations.

Originality/value: Text-mining techniques for customer satisfaction is a well-studied field. Since its inception, it has been used to do sentiment analysis, including transformers. However, to the best of the authors' knowledge, the use of "off-the-shelf" pre-trained transformer models in this context was not found, particularly in the proposed pipeline, with a final ensemble model to leverage and improve the different predictions of the different transformers.

Keywords: Customer Review, Customer Satisfaction, Transformers, Machine Learning.

Paper type: Research paper

1. INTRODUCTION

Online customer reviews are nowadays a crucial component for assessing customer satisfaction. They enable the automated monitoring, measuring, and analyzing of customer feedback, helping companies to understand the market needs (Dickinger & Mazanec, 2015).

This review process is usually based on star ratings and text information systems to identify the sentiment analysis. In this context, sentiment analysis can be defined as the natural language processing task of extracting the attitude of a customer on a considered subject from texts (Liu, 2012).

In this paper, the use of pre-trained transformer models (Vaswani et al., 2017) is investigated as a novel approach for this task by analyzing five such models to identify the sentiment of a given customer review. Furthermore, an additional neural network is also considered as part of an ensemble approach.

The remainder of this paper is organized as follows: Section 2 presents the related work, Section 3 describes the transformer models used, evaluation metrics, and how the data was collected and pre-processed. Then, in section 4 the experimental results and their discussion are presented. Finally, Section 5 presents the main conclusions and future work directions.

2. THEORETICAL BACKGROUND

Customer satisfaction is the positive state of customers when their needs are met by the good or service they buy or use (Juran & Godfrey, 1998). Setting specific goals for customer satisfaction helps keep the organization customer-focused. Implementing these goals requires a good amount of solid data about the current level of satisfaction/dissatisfaction and what factors will contribute to increased satisfaction. If the most important customer needs are known, the organization's strategies can be altered to meet those needs more effectively (Juran & Godfrey, 1998).

Accordingly, organizations have adopted performance excellence programs that include business process management as a means of adapting to changing customer needs. This concept is emphasized in the ISO 9001, the leading international standard for the development of quality management systems by the International Organization for Standardization (*ISO*, 2015), where metrics are being used increasingly to characterize product quality and customer satisfaction more effectively.

Internet retailing and e-commerce have provided new opportunities for improved and more accurate customer behavior analysis as opposed to the traditional expensive and time-consuming offline marketing research (Wang et al., 2018).

By monitoring process performance concerning customer requirements, the process owner can identify gaps between what is being delivered and what is required for full customer satisfaction. These gaps are targets for quality improvement efforts (Juran & Godfrey, 1998). Online review platforms and social media can be used to assess customer requirements. These platforms are a popular way for users to post reviews by expressing their opinions towards a product or service, either quantitatively or qualitatively. Therefore, they provide information to trigger quality improvement efforts.

Online reviews within customer review platforms tend to be accompanied by a star rating, which has become a common approach for users to give their feedback quantitatively, providing other buyers with an idea of how people generally felt about a product (Jiang & Zubiaga, 2019; Peal et al., 2022). Usually, this star rating system is based on a Likert scale of 1–5 stars, as a typical Amazon product page is currently constituted. Such data is often used as a gold standard while evaluating sentiment extraction/identification (Mejova, 2009).

Sentiment analysis, subjectivity analysis, opinion mining, or appraisal extraction, is a field to study subjective elements - usually single words, phrases, or sentences - to identify and extract the sentiment (Mejova, 2009). Within the literature, many papers dealt with sentiment analysis in e-commerce, marketing, advertising, politics, market research, and any other research. For example, text analytics within online reviews may be used to improve product design, i.e., providing feedback to designers on product features /attributes that showed more impact on customer satisfaction (Wang et al., 2018), or even to quality surveillance and safety hazard detection (Mummalaneni et al., 2018). Sentiment analysis is important because emotions and attitudes towards a topic can become actionable pieces of information useful in numerous areas of business and research. It helps monitor, measure, and analyze customer feedback, helping companies to understand the market needs, target customer segments, and benchmark their position against competitors (Mejova, 2009). Moreover, it saves time and effort since the process of sentiment extraction is fully automated.

Sentiment analysis is becoming more popular, accessible, and affordable while technologies such as artificial intelligence, deep learning, machine learning techniques, and natural language processing technologies are developing. It has been addressed using several approaches such as statistical models, regression models like Bag of Words (BOW), Linear Support Vector Machine (LSVM), Facebook *fast*Text, and Long Short-Term Memory (LSTM) models (Chinnalagu & Durairaj, 2021). Machine learning algorithms (ML) like LDA, KNN, CART, NB, and SVM along with deep learning neural networks (DNN) have also been explored in this context (Gadri et al., 2021).

All these technics predate the transformer model, which has been enjoying remarkable success in all NLP tasks since the publication of the paper “Attention is all that you need” (Vaswani et al., 2017). In this paper it is proposed, first, to use “off-the-shelf” pretrained transformer models in this context to curb the high level of resources required to train transformers from scratch. Second, it is added a final ensemble model to choose the best prediction from the five ones provided by the transformers.

3. RESEARCH METHODOLOGY

Data preparation

From the “Amazon Automotive Dataset”, a single product with 32134 reviews was selected. From each review, both the written text and the 5-points Likert rating given by the customers were considered. The 5 points rating was mapped to a 3-point according to the arrangements presented in Table 1.

Table 1 – Rating consolidation arrangement

Customer given rating	Sentiment Class
1 and 2	Negative
3	Neutral
4 and 5	Positive

Evaluation metrics

Model predictions of a review sentiment (negative, neutral, and positive) are compared to the rating given by the customer. Accuracy, precision, recall, and F1-score are calculated over each possible sentiment according to the following metrics:

$$\text{Accuracy} = \frac{\text{True Positives} + \text{True Negatives}}{\text{True Positives} + \text{True Negatives} + \text{False Positives} + \text{False Negatives}} \quad (1)$$

$$\text{Precision} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Positives}} \quad (2)$$

$$\text{Recall} = \frac{\text{True Positives}}{\text{True Positives} + \text{False Negatives}} \quad (3)$$

$$\text{F1-Score} = 2 \times \frac{\text{Precision} \times \text{Recall}}{\text{Precision} + \text{Recall}} \quad (4)$$

Accuracy refers to the number of correctly predicted instances among the total number of instances, precision refers to the fraction of relevant results, recall is the fraction of positive labels correctly identified by the model, and F1-Score is the harmonic mean of precision and recall. Accuracy is an intuitive and easy metric but it is not well suited in multiclass classification problems and when the datasets are imbalanced being F1-Score the best option (Grandini et al., 2020; Noori, 2021).

Methods

Five transformer models (Table 2) are run through the Amazon database of automotive products for opinion mining/sentiment analysis of the written reviews, which are then compared with the quantitative rating given by the customer.

These models were chosen from the *hugging face* repository[1] not only based on popularity but also considering the dataset used in the fine-tuning process. Fine-tuning is the process of taking a model that already has a built-in representation of language and then training it again in a specific task, i.e., question answering or sentiment analysis. All the models are fine-tuned for the task of sentiment analysis, e.g., on financial texts and Twitter data.

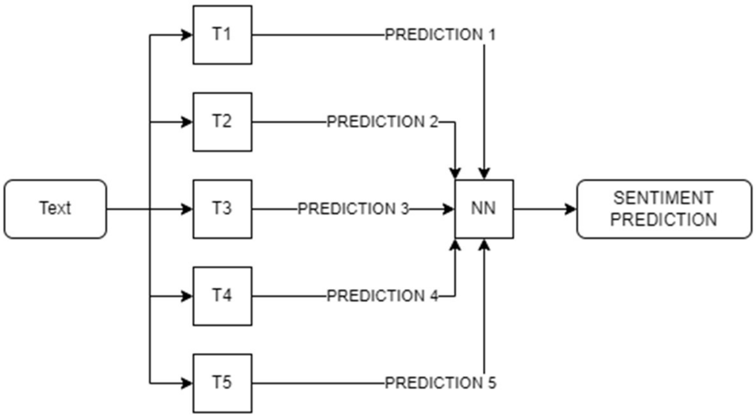
Table 2 - Transformer Models

Model	**Hugginface/model id**
T1	mrm8488/distilroberta-finetuned-financial-news-sentiment-analysis
T2	yiyanghkust/finbert-tone
T3	ProsusAI/finbert
T4	cardiffnlp/twitter-roberta-base-sentiment
T5	oferweintraub/bert-base-finance-sentiment-noisy-search

[1] https://huggingface.co/models ; https://huggingface.co/{Hugginface model id}

To improve performance a neural network (NN) model was added. It was trained on the combined predictions of the transformers thus building a pipeline (Figure 1) where a review is fed to the transformers. The predictions coming from the five transformers are the input of the ensemble model, making the final prediction of sentiment present in that review.

Figure 1 - Ensemble Pipeline



4. RESULTS AND DISCUSSION

Experiments were carried out by applying each transformer to the dataset and comparing its prediction with the ground truth represented by the mapped rating entered by the customer. The accuracy for each model is presented in Table 3. The model with higher accuracy is the ensemble model (NN), 91% followed by T4 with 84%.

Table 3 – Models' accuracy

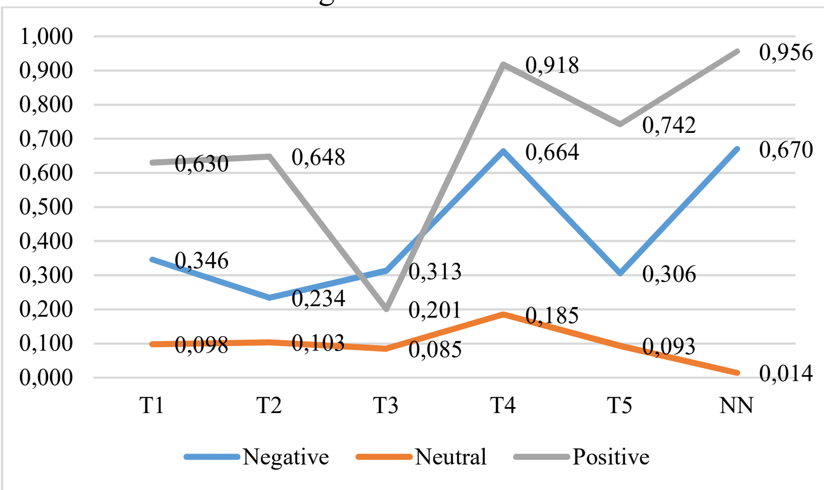
Model	Accuracy
T1	0,46
T2	0,47
T3	0,15
T4	0,84
T5	0,59
NN	0,91

Table 4 shows precision, recall, and F1 score for each model and class. Higher values of metrics imply better performance. Visually, according to the color scale from red to green, entries are colored from worst to the best performance, respectively. The results show that although models are based on the same neural network architecture, performances are very dissimilar.

Table 4 – Models' performance

		Precision	**Recall**	**F1-score**
Negative	T1	0,53	0,26	0,35
	T2	0,31	0,19	0,23
	T3	0,63	0,21	0,31
	T4	0,61	0,72	0,66
	T5	0,24	0,43	0,31
	NN	0,63	0,72	0,67
Neutral	T1	0,05	0,63	0,10
	T2	0,06	0,64	0,10
	T3	0,05	0,87	0,09
	T4	0,13	0,34	0,19
	T5	0,05	0,33	0,09
	NN	0,42	0,01	0,01
Positive	T1	0,95	0,47	0,63
	T2	0,96	0,49	0,65
	T3	0,97	0,11	0,20
	T4	0,97	0,87	0,92
	T5	0,93	0,62	0,74
	NN	0,94	0,97	0,96

Figure 2 - F1 score



As depicted in Figure 2, for negative and positive sentiment, the NN and T4 models were the ones performing better for all metrics (Precision, Recall, F1 Score). For the neutral sentiment, on the other hand, no model performed well. Model T3 (Table 4) has a high value of recall on neutral sentiment but a very low precision. This happens because this model attributes neutral sentiment to the majority of text inputs. Results show the importance of choosing F1-Score over the accuracy or just precision/recall when datasets are imbalanced such as in this case.

5. CONCLUSIONS

The results indicate that although transformers can be a useful tool to extract customer satisfaction from text, choosing an appropriate model is critical to obtaining reliable metrics. Model T4 shows interesting results in identifying both the negative and positive sentiment while all models perform poorly in identifying a neutral sentiment. The ensemble model improves the overall results and is the best at positive and negative classification.

Results show that while the identification of positive and negative sentiment is effective, based on the text data of customer reviews using transformers, it can be improved using an ensemble approach without the need to fine-tune the transformers. The methodology presented can be yet another tool incorporated into the quality management ecosystem. Even though this approach was done based on customer reviews, no obstacles were found to using the findings to apply them to other areas as depicted in “practical implications”. Finally, this paper shows that it is possible to deploy an automated system using the latest technologies in NLP without the requirement of having significant resources.

In future work, the aim is to investigate if the datasets used to fine-tune the language models have a significant impact on the downstream task subdomain since all transformers used in this paper were trained on sentiment classification and have similar architecture, yet their performance is very disparate.

Another line of future investigation can be found on knowing the motives presented by the customers to support their classification, something we do not cover in this paper. It is very important for a company to know the reasons presented by their customers on reviews, not only on the positive side, what the company is doing right and keep the focus, but also why are customers unhappy, to correct company actions. It would be of value to investigate if transformers trained on NLP tasks like summarization or text classification could be useful to automatically distill the main clusters of satisfaction and dissatisfaction by the customers, again, using “off-the-shelf models”.

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REFERENCES

Chinnalagu, A., & Durairaj, A. K. (2021). Context-based sentiment analysis on customer reviews using machine learning linear models. *PeerJ Computer Science*, *7*, e813. https://doi.org/10.7717/peerj-cs.813

Dickinger, A., & Mazanec, J. A. (2015). Significant word items in hotel guest reviews: A feature extraction approach. *Tourism Recreation Research*, *40*(3), 353–363. https://doi.org/10.1080/02508281.2015.1079964

Gadri, S., Chabira, S., Ould Mehieddine, S., & Herizi, K. (2021). Sentiment Analysis: Developing an Efficient Model Based on Machine Learning and Deep Learning Approaches. *International Conference on Intelligent Computing & Optimization*, 237–247.

Grandini, M., Bagli, E., & Visani, G. (2020). Metrics for Multi-Class Classification: An Overview. *ArXiv:2008.05756 [Cs, Stat]*. http://arxiv.org/abs/2008.05756

ISO 9001:2015, "Quality Management Systems - Requirements," International Organization for Standardization, Geneva, Switzerland, 2015, www.iso.org

Jiang, A., & Zubiaga, A. (2019). Leveraging aspect phrase embeddings for cross-domain review rating prediction. *PeerJ Computer Science*, *2019*(10), 1–21. https://doi.org/10.7717/peerj-cs.225

Juran, J. M., & Godfrey, A. B. (1998). *Juran's Quality Handbook* (5th edition). McGraw-Hill Companies.

Liu, B. (2012). Sentiment Analysis and Opinion Mining. *Synthesis Lectures on Human Language Technologies*, *5*(1), 1–167. https://doi.org/10.2200/S00416ED1V01Y201204HLT016

Mejova, Y. (2009). *Sentiment Analysis: An Overview*.

Mummalaneni, V., Gruss, R., Goldberg, D. M., Ehsani, J. P., & Abrahams, A. S. (2018). Social media analytics for quality surveillance and safety hazard detection in baby cribs. *Safety Science*, *104*(January), 260–268. https://doi.org/10.1016/j.ssci.2018.01.003

Noori, B. (2021). Classification of Customer Reviews Using Machine Learning Algorithms. *Applied Artificial Intelligence*, *35*(8), 567–588. https://doi.org/10.1080/08839514.2021.1922843

Peal, M., Hossain, M. S., & Chen, J. (2022). Summarizing consumer reviews. *Journal of Intelligent Information Systems*. https://doi.org/10.1007/s10844-022-00694-9

Vaswani, A., Shazeer, N., Parmar, N., Uszkoreit, J., Jones, L., Gomez, A. N., Kaiser, L., & Polusukhin, I. (2017). Attention Is All You Need Ashish. *31st Conference on Neural Information Processing Systems (NIPS 2017)*, *30*. https://doi.org/10.1109/2943.974352

Wang, Y., Lu, X., & Tan, Y. (2018). Impact of product attributes on customer satisfaction: An analysis of online reviews for washing machines. *Electronic Commerce Research and Applications*, *29*, 1–11. https://doi.org/10.1016/j.elerap.2018.03.003

Development of an AI-based workflow to support competency-based resource planning of industrial projects

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STRUCTURED ABSTRACT

Purpose – This paper explores the possibility of using tools and algorithms from the fields of machine learning and computational linguistics to assist the project manager in prospectively accurate estimation of resources in the project planning phase using the information from quality management systems and older completed projects.

Design/methodology/approach – A systematic analysis of the literature and research projects was carried out to survey the current application areas of NLP. For this purpose, a search in scientific databases such as GEPRIS, Google Scholar, IEEE Xplore, ScienceDirect, and SpringerLink was carried out in May 2021 for the observation period from 2012 to 2021.

Findings – The potential of NLP in combination with machine learning in the form of an AI workflow as a support for project management concerning competence-based resource planning in software development projects has been overlooked.

Originality/value – This is a systematic approach for competency-based project planning of industrial projects, which uses modern IT-based solutions from the field of artificial intelligence (AI) for support. By querying and analyzing information from quality management systems of the company regarding project roles, competencies of team members, etc. and combining and comparing this information with the company's already completed projects, conclusions can be drawn regarding future projects.

Keywords: Quality Management Systems, Quality 4.0, Competency Management, Project Planning, Artificial Intelligence

Paper type: Research paper

INTRODUCTION

In scientific language, "complexity" has become a widely used term to describe the complications of life in contemporary societies. For all its metaphorical usage, this is a social finding that is remarkable in itself (Adolf, 2017). Complexity is a system property with two dimensions, the variety of elements and the variety of relations between these elements (Luhmann, 2005).

Regarding industry and companies, complexity has two levels, external and internal complexity of a company, each with diverse causes. External causes can be traced back to market and technology changes, but also to societal requirements and competitive and excellence pressures. In parallel, the internal causes of complexity can be grouped according to systems, strategies, structures, and processes within the company. Figure 1 visualizes the two types of complexity and the respective causes (Thiebes & Plankert, 2014).

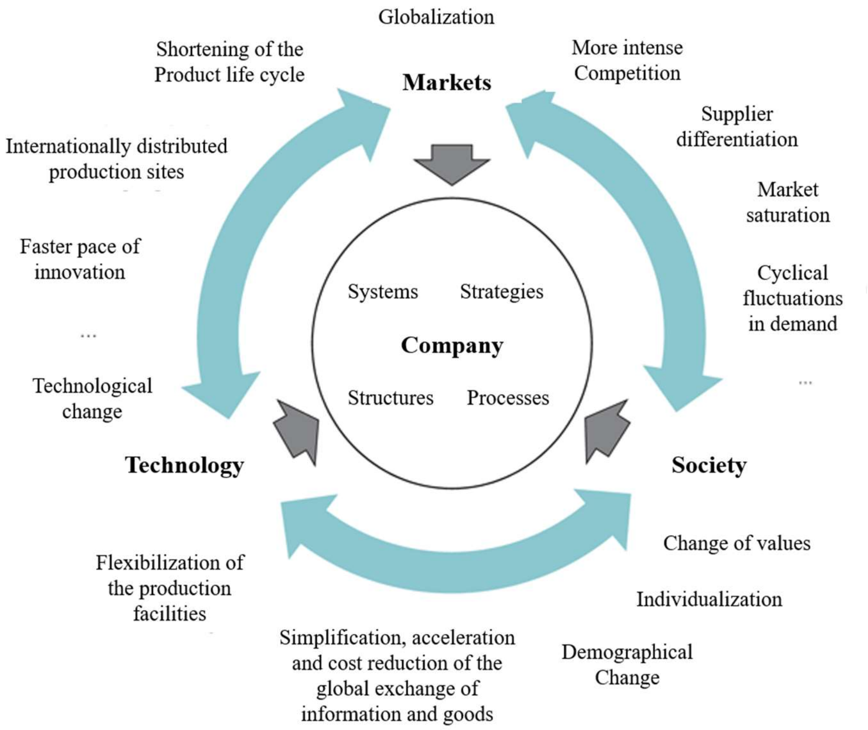

Figure 1 – Causes of increasing internal and external complexity (Thiebes & Plankert, 2014)

The key question here is how a company should be structured from an internal perspective to handle complexity to be able to perceive and fulfill external requirements and the resulting external complexity. This means taking up the product and flexibility requirements, which are imposed by the market and other change and trend drivers, and fulfilling them internally as efficiently as possible via organizational structures, processes, and value creation strategies. Such requirements are often responded to just with some new case-specific solutions at the process, organizational, or IT level and hardly any generic solution is researched (Schatz *et al.*, 2014).

The resulting extra costs from complexity can only be made transparent and reduced in a targeted manner with great effort (Wilson & Perumal, 2010). The complexity affects directly the product development process and leads to an increase in complexity for industrial projects and tasks. In this research, the focus is on embedded software development and related processes in the automotive industry. Due to the heavy cross-linking of the individual processes, tasks, different influencing variables, and the involved departments in the projects the failure rate increases (Kapici, 2005). On the one hand, an increased number of failures can always affect the quality or even the safety of a product, as it can lead to the failure of a system and affect its use (Gembrys & Herrmann, 2009). On the other hand, it can have an impact on the entire company, since quality and safety are mandatory requirements for the success of an industrial project and thus of the company carrying it out (Hartwig, 2010). Failure to meet customer requirements can have far-reaching consequences such as customer churn and damage to the company's image (Vöcking, 2008). As a result, companies carrying out industrial projects must not only make decisions regarding resources, competencies, time, and money in project planning and project execution more and more quickly. But also, overcome the challenge that industrial projects are not easy to estimate prospectively due to their complexity, in order to maintain the market position against the competition (S.Phabmixay *et al.*, 2018). This situation leads to industrial projects being delayed or failing (Grimm, 2003; Khare *et al.*, 2017) and this should be avoided. Figure 2 summarizes the problem in the form of a causal chain of the above problems.

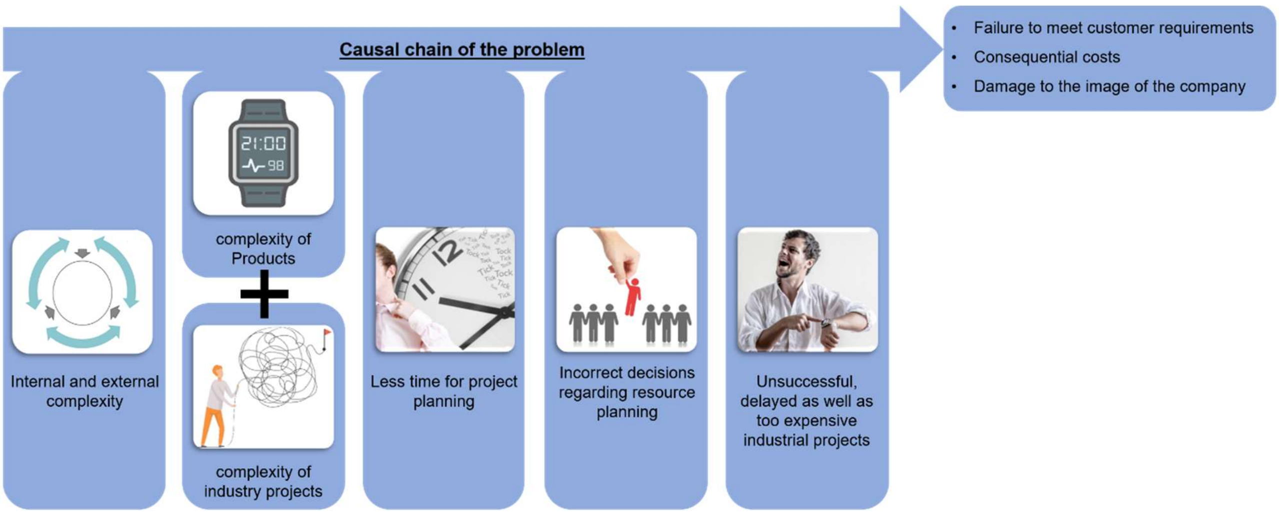

Figure 2 – Causal chain of the problems regarding the complexity of industry projects

There are enough examples of projects in the industry that were planned incorrectly due to their complexity, whose resources were not distributed efficiently and the teams were not put together concerning their actual competencies and intersections, which is why the stakeholder requirements and project goals based on them could not be achieved (Lange, 2015) and it lead to the consequential costs due to the not fulfilment of customer requirements or also called poor-quality costs (Harrington, 1987). But aren't there existing approaches or methods that enable target-oriented resource planning in the project planning phase for complex projects? Of course, a variety of classic, agile, and hybrid approaches to project management (PM) have been established in both science and technology, which deal, among other things, with targeted resource planning. However, according to (Kuster *et al.*, 2019), regardless of the project approach, whether classical or agile, an effort tolerance of -50%/+100% in early phases and ±10% in later phases must be expected in the different project phases. However, this tolerance is expected to be kept as low as possible to avoid possible unplanned efforts. Thus, the need for more accurate estimation or planning of resources in the early phases of project management emerges. But how could the estimation be improved? Which factors influence the estimate in reality?

One possible solution is to develop a systematic approach for competency-based project planning, which uses modern IT-based solutions from the field of artificial intelligence (AI) for supporting project management (Buxmann, 2019). An interface between linguistics and computer science leads to an AI component called Natural Language Processing (NLP), which allows the computer to automatically convert a natural language input (voice, text, image, etc.) into a standardized format and use it for subsequent actions such as machine learning processes and then decision making (Wess, 2019). The project documentation available at the end of a completed project, e.g., project status report, lessons learned, email exchanges, and meeting minutes contains useful information about the progress of the project from the initial phase to completion. By analyzing this information, correlations of different indicators can be derived, which play a role in whether a project is delayed and thus unsuccessful. But how could, for example, the entire e-mail exchange of a project be analyzed so that the important correlations of the information could be derived? NLP thus opens up the possibility of automatically and efficiently interpreting a large amount of unstructured data written in natural language according to certain factors or indicators, putting it into a structured form, and using it to support decision-making (Wess, 2019). This research takes this hypothesis as its base and analyses the potential of NLP concerning competence-based project planning.

RESEARCH METHODOLOGY

A systematic analysis of the literature and research projects was carried out to determine the current application areas of NLP. For this purpose, research in scientific databases, such as GEPRIS, Google Scholar, IEEE Xplore, ScienceDirect, and SpringerLink in the period under consideration from 2012 to 2021 was carried out. This search was narrowed down by taking the following two aspects into account: Only sources were considered, where it is clear that NLP stands for Natural Language Processing (Not other terms, such as Neuro-Linguistic Programming) and research has been conducted in a specific field on the uses and applications of NLP. Therefore, the studies that only deal with NLP in general or further development of NLP techniques were not considered for the time being. Table 1 presents the results of this research or the application areas of NLP.

Table 1 – Application areas of NLP and the respective number of analyzed studies

Application area	Number of studies	Application area	Number of studies
Medical and Health	31	Biomedicine	4
Knowledge Management	29	Computer science	3
Engineering	20	Project Management	3
Linguistics	17	Others	9
Social science	5		

As can already be seen from the results of the research in Table 1, NLP approaches have become very well established in the field of Medical and, knowledge management as well as in engineering. However, this listing does not include any studies, which are focusing on NLP-supported competency-based resource planning in software development projects. But there were 10 international and 2 national research projects identified in this research that address this problem area. Subsequently, the identified studies were evaluated based on the following five topic areas that can be derived from the above problem area. The derived topic areas serve to more clearly distinguish this research project from the other research and to better demonstrate the scientific gap:

Topic 1 (Information structure): The type of information required for planning resources for a project should be investigated and identified. Subsequently, the findings are to be reproduced in the form of an information structure so that the computer can read and understand relevant information for resource planning. Furthermore, it is necessary to find out in which form or in which documentation this information can be found. This is necessary for the derivation of the indicators that influence the resource planning of the industrial project.

Topic 2 (AI workflow): An AI workflow should be developed, which analyses the different project documentation in a target-oriented manner. A user-friendly and interactive frontend will be developed, to ease the access and editing of information and results.

Topic 3 (Integration of NLP in workflow): The appropriate use of an NLP system, including the training phase of the algorithm, should be investigated in order to enable and also facilitate the processing of extensive project documentation.

Topic 4 (Interpretation results): It is to be examined how the findings from the NLP analysis are to be combined with existing enterprise information concerning the resources such as personal competencies. This is important regarding further use and interpretation of the NLP results for competency-based resource planning.

Topic 5 (Validation of the workflow): The question is to what extent the results of the AI workflow are plausible. Therefore, the results are to be evaluated for their usefulness for project management resource planning and the weaknesses of the AI workflow are to be identified.

Table 2 – Evaluation of state of art regarding the identified 5 topics
(Legends: ○=not covered, ◑=partially covered, ●=fully covered)

Nr.	National	Source	T1	T2	T3	T4	T5
1	Analysis and evaluation of weighted requirements in technical specifications	(Zwirn, 2013)	○	◑	●	●	◑
2	Ontology-based dependency analysis in the project requirements specification	(Zichler & Helke, 2017)	○	◑	●	◑	●
Nr.	**International**	**Source**	**T1**	**T2**	**T3**	**T4**	**T5**
3	Improving agile requirements: The Quality User Story framework and tool	(Lucassen *et al.*, 2016)	○	◑	◑	◑	●
4	Approximation of COSMIC functional size to support early effort estimation in Agile	(Hussain *et al.*, 2013)	○	◑	●	●	◑
5	The NORMAP Methodology	(Farid, 2012)	○	◑	◑	○	◑
6	NORMATIC: A visual tool for modeling Non-Functional Requirements in agile processes	(Farid & Mitropoulos, 2012)	○	◑	●	◑	●
7	Automatic Generation of Test Cases for Agile using Natural Language Processing	(Rane, 2017)	○	●	●	○	●
8	Natural Language Processing and Machine Learning Methods for Software Development Effort Estimation	(IONESCU *et al.*, 2017)	◑	●	●	◑	◑
9	Requirements Complexity Definition and Classification using Natural Language Processing	(Sundararajan *et al.*, 2018)	○	◑	●	○	◑
10	Simplified Agile Software Project Selection Model Using Natural Language Processing Based Upon Agile Team Skills	(Sharma *et al.*, 2019)	◑	●	●	◑	◑
11	Support for traceability management of software artifacts using Natural Language Processing	(Arunthavanathan *et al.*, 2016)	○	●	●	◑	●
12	Smart Project Management: Interactive Platform Using Natural Language Processing Technology	(Chen *et al.*, 2021)	◑	◑	●	○	◑

All 12 studies listed in table 2 deal with AI workflows and NLP, but do not fully cover all defined five topics. So, they should be evaluated concerning five topics. The first two national studies focus on requirements engineering and use NLP pipelines to weight requirements and analyze their dependencies, respectively. The third study uses NLP techniques and presents in a framework names AQUSA the possibility of identifying and improving unprecise User Stories. In the 4th study, COSMIC, the requirements for a software development project are read and analyzed using NLP to better estimate the project size and make a more accurate prospective effort estimate. As next, both studies of NORMAP and NORMATIC deal exclusively with the analysis of non-functional requirements and modeling of the requirements. In the 7th study, NLP techniques are used to generate test cases for the developed software based on User Stories. Study 8 analyzes the completed tasks in a project and combines the extracted information with the information about task completion time. Based on this, the project effort for a similar project can be estimated prospectively by adding up the times of the respective tasks. Study 9 puts the focus also on requirements. It analyses the requirement description with NLP to extract appropriate keywords including a weighting for each requirement. Thus, requirements can be classified by complexity level and used in estimating, planning, and defining the development and test execution sequence. Study 10 aims at a competence analysis for agile teams. For this purpose, software development projects and agile teams are attributed and confronted in form of a square matrix in order to calculate risk in terms of the success of the project, if the selected team is applied to the project. Study 11 is mainly concerned with change management. For this, a tool called SAT-Analyzer was developed to track changes in software artifacts across requirements specifications, Unified Modeling Language (UML) diagrams, and source codes by creating a structured format for these documents and analyzing them with NLP. The latest study from 2021 proposes a project management platform to extract keywords by analyzing project documentation. The concept allows for a reduction in manpower and human failure, resolving misunderstandings or disputes through real-time and precision communication, and a solution for efficient document management in construction projects.

In summary, considering the above causal chain of the problem (s. Figure 2), the potential of NLP in the analysis and preparation of information, and the results of the analyzing the state of the art regarding this problem area, an interdisciplinary need for research regarding the implementation of AI components, such as NLP, in project management to optimize resource planning in the early phases of the project. This should provide a basis not only to accelerate decisions concerning competence-based resource planning but also to avoid wrong decisions in the planning phase of project management.

RESULTS

To cover the identified scientific gap, the main objective is derived based on the literature: Development of an AI-based workflow to support competency-based resource planning of industrial projects. This objective is intended to enable the project manager to make flawless decisions at an early stage and in a shorter time. The decision-making is based on a systematic analysis of the documentation of previous projects of the company, to ensure the success of the project. Nevertheless, this is only possible if suitable project teams are deployed at the right time of the project according to their competencies and expertise.

However, the research objective is still very diverse and therefore it is necessary to define sub-objectives based on the previously mentioned topics. The following 4 sub-goals were derived from the 5 topic areas of this research.

Subgoal 1 (from Topic 1): Development of an information structure to identify the relevant project information concerning resource planning. The different project information is listed in different project documents. However, not all documentation in the project environment contains the information that is relevant for resource planning (e.g., technical drawings are not directly relevant). Therefore, a pool of relevant project documentation containing resource-related information is to be created first. However, by no means all information contained in the relevant documents contributes to resource planning. In order to find the relevant information from this collection pool of relevant project documentation and then make it available for further processing, it is necessary to develop an information structure that identifies exactly what information is important for resource planning.

Subgoal 2 (from Topic 2): Derivation of indicators (labels) for competency-based resource planning in project management that have an impact on project success. Not all information related to resource planning plays a role in determining whether wrong decisions are made and, as a result, a project is delayed or fails. For this reason, indicators should be derived based on the information listed in the information structure that has a direct relationship to project success and relate to the area of competency-based resource planning of industrial projects. The derivation of these indicators (labels) will serve as a basis for examining the documentation of all the company's projects. Furthermore, the interactions and relations of the derived labels among each other, as well as their interrelationship with the project environment, are to be considered or analyzed. In this respect, it is helpful if a project is understood as a socio-technical system. Then it is possible to identify and model the elements of the system and their interrelations within the system. For this purpose, the project should be modeled based on eDeCoDe. The eDeCoDe model is used to master the complexity across socio-technical systems and a better understanding of interconnections and relations of different system elements as well as their attributes (Schlueter *et al.*, 2018; Mistler, 2021).

Subgoal 3 (from Topics 2 and 3): Development of a suitable NLP-supported procedure for analyzing the documentation and structuring the information concerning the derived labels. Manual processing of all relevant information from previous projects of the company is very time-consuming and almost impossible due to the volume and different forms. For this reason, an NLP pipeline is to be set up that examines the documentation from all of the company's projects and categorizes it according to the previously derived indicators or labels. In this way, it can be ensured to what extent the labels modeled in sub-goal 2 based on the eDeCoDe logic and their interrelationships play a role in the decision-making process regarding competency-based resource planning.

Subgoal 4 (from Topics 4 and 5): Development of an effective AI workflow for interpreting the results from the NLP analysis and incorporating them into project management resource planning. After the NLP system has analyzed the information, the results should be reassembled, interpreted, and rendered in a reasonable form that can be understood and used by humans. A systematic workflow should be developed to convert the results of the analysis into usable knowledge and then present it in a suitable form. In this way, the project manager can use these findings as decision support in order to make a quick and flawless decision about resource planning in the upcoming project. To realize the way to achieve the sub-goals mentioned above, a solution approach consists of three logical phases is developed: 1- Collection of the required documentation (preparation), 2- analysis of this documentation (NLP), and 3- a collection of useful information (prediction) to support the project management in a competency-based resource planning. These three phases are realized in four work packages (WP), which are visualized in Figure 3. The first three WPs serve to cover the objective of this research and within the last WP, the developed AI workflow will be validated.

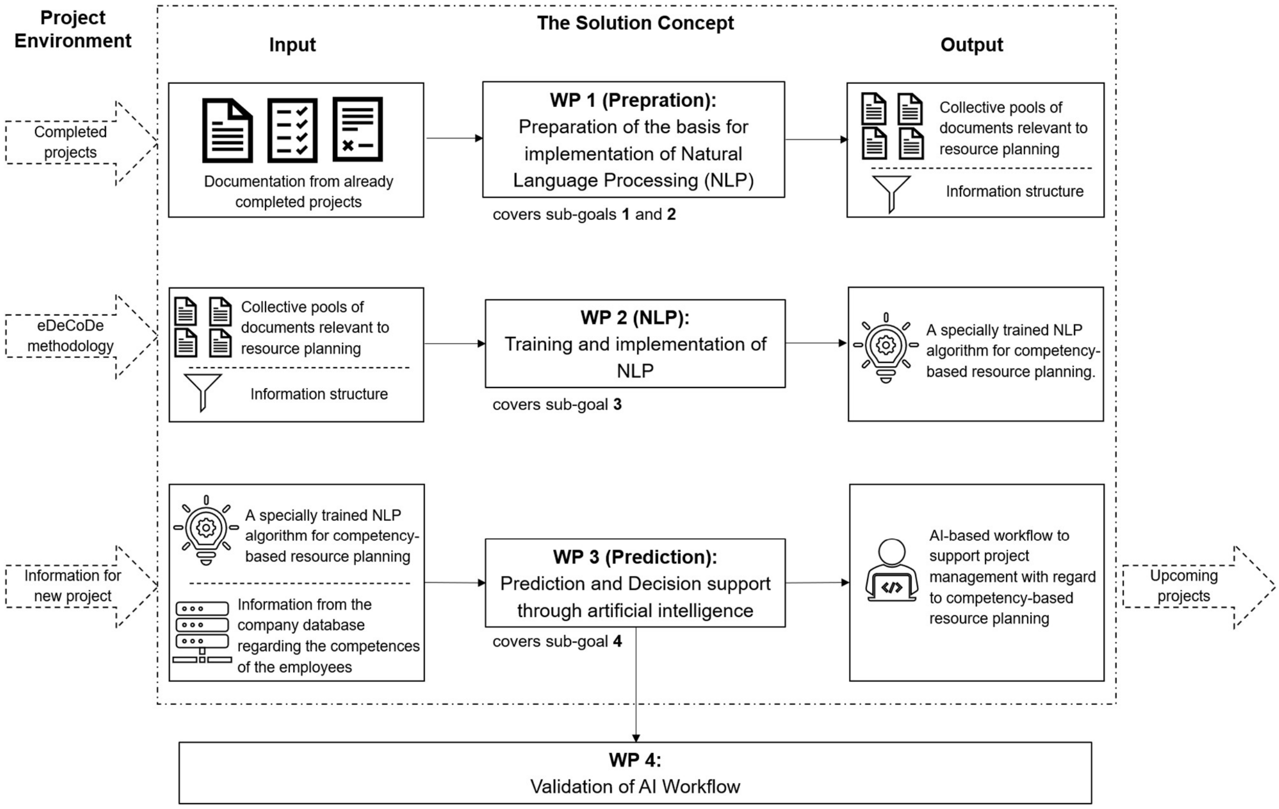

Figure 3 – Schematic representation of the solution concept

Work Package 1 (Preparation): In this first step, it should be determined which documents in a project and also outside the project, at the organizational level, normally contain resource planning information. Not all project documents are resource-related. Information such as project duration, number of project members, organizational units involved, competence profile of the project members, project roles, etc. belongs to the important information for resource planning. Such information can usually be found in project documents such as the project manual, quality management plan, and feasibility analysis, but also in project-independent documents from different information systems of the company, such as digital personnel files, skills databases, accounting, etc. But the information in documents is usually not structured and should be analyzed and sorted.

In order to be able to analyze the collected documentation using NLP and to generate insights into competency-based resource planning, the information from the text of the documents should be filtered and categorized. For this purpose, a targeted information structure should be developed based on the literature, which can distinguish and categorize the information contained in the documents concerning the different human resources, such as professional or methodological competencies. Based on these filters, the NLP system can in the next step read, categorize or label the collected documents and finally understand the interrelationships.

Work Package 2 (NLP): With the preliminary work from WP1, a basis for carrying out a successful NLP analysis has been created. Figure 4 visualizes the NLP pipeline with the different analyses of the text.

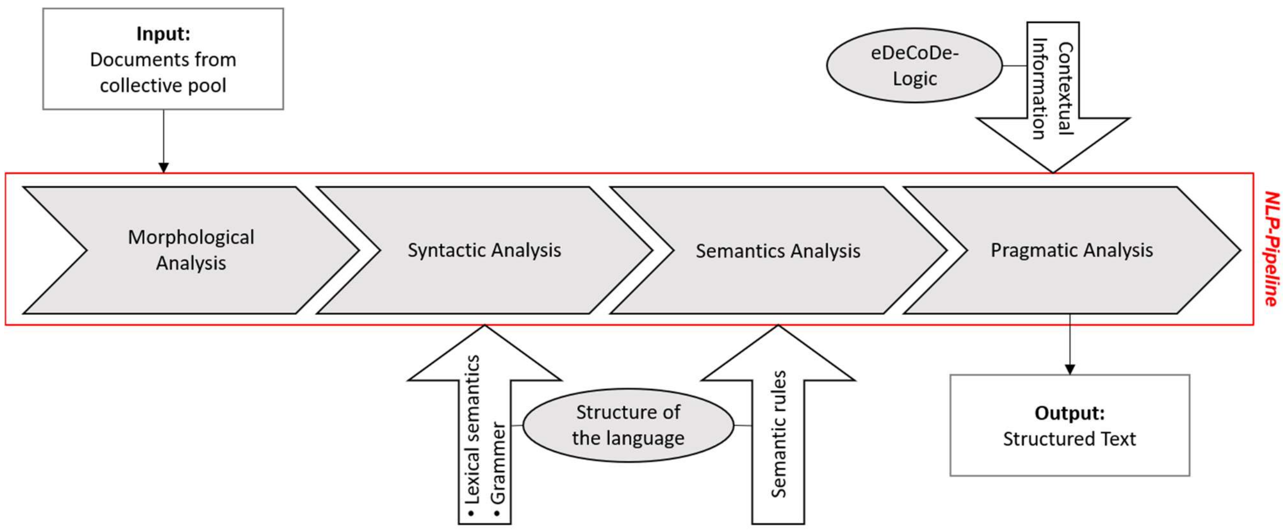

Figure 4 – The NLP pipeline; Input, output, and analyses

When NLP is carried out, the input text, which is normally written by a human, is classified in the form of morphological processing according to word types and word forms (e.g., noun, article, verb, etc.) as well as the structure of the word forms (e.g., case, person, numerous, tense, etc.) and traced back to their basic form. Then, through a syntactic analysis, the grammar is consulted and the sentence is structured according to grammar rules. Using semantic analysis, the algorithm first looks at the meaning of the words, then the contextual information is considered by a pragmatic analysis and the meaning of the words from the semantic analysis is completed (Kumar, 2011). This means that a connection is made to preceding or following sentences so that preceding sentences gain meaning through further information. This is to ensure that what is said is interpreted exactly as it is meant. This helps in this respect, as it is intended to highlight the context better, which, however, requires additional knowledge from the problem field that does not necessarily arise from general linguistic knowledge (Kumar, 2011). It is precisely at this point that the importance of the previously developed information structure in connection with the eDeCoDe methodology becomes clear, as it provides the algorithm with additional knowledge from the problem field. This is needed in the pragmatic analysis in order to understand the contextual connections and the discourse in general. Thus, the algorithm can assign categories to the labels in the text and at the same time understand the connections of different categories with the overall context and ultimately make a decision on this basis. The logic is implemented using two relation matrices from the eDeCoDe toolbox, the DomainMappingMatrix (DMM) and the DesignStructureMatrix (DSM), and then taught to the algorithm in the training phase (Winzer, 2016). A successful NLP implementation depends on the training phase (Kumar, 2011).

During the training phase, the algorithm should be trained based on the chosen language (German in this work) in terms of the lexical structure and grammar of the language. Furthermore, the algorithm should be able to understand and analyze the language-independent contexts from the actual problem field in the company.

Work Package 3 (Prediction): After successful training and execution of the NLP pipeline, the algorithm will be able to analyze arbitrary texts in terms of resource planning and people's competencies, and in particular to understand the actual meaning of sentences and contextual relationships in a text. The trained algorithm will be integrated into a user-friendly AI workflow to make predictions about resource planning in a new project based on its experience by analyzing previous project documents. For this purpose, an input mask should be designed for the user, which requests the information of the new project from the user, sends it to the algorithm, and accordingly displays the predictions provided by the algorithm for the user.

At this point, it is necessary to use an application programming interface (API) to retrieve the current data on staff workload, their skills profile, and experience from the existing company database. Figure 5 illustrates the concept of AI workflow on two levels front-end and back-end.

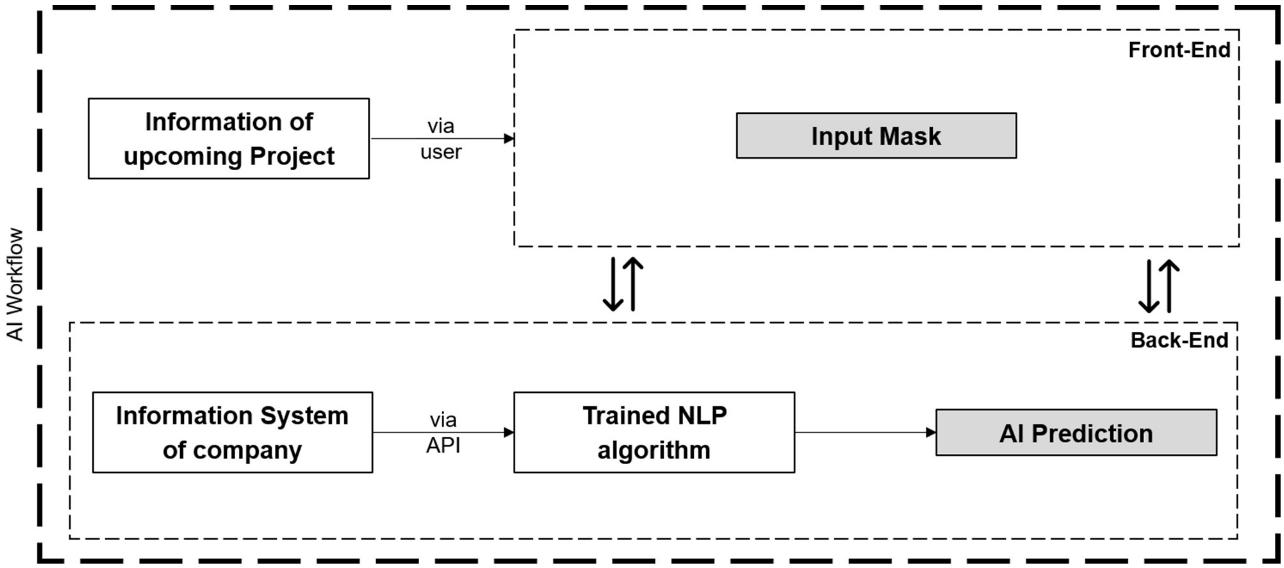

Figure 5 – The AI Workflow

So, the user can pass on a rough plan regarding resources to the algorithm via the input mask and ask whether the new project could be successful (front-end). Based on this, he can adjust his plan again and again and see how the success rate changes. Since the algorithm has analyzed the company's previously completed projects concerning the planned resources and the success rate of the respective projects, it can make a prediction in this regard based on the company's internal know-how (back-end).

Work Package 4 (Validation): The fourth work package serves to validate and test the previously developed concept and AI workflow. This work package is essential because only through validation and testing in the industry can it be shown which weaknesses this solution concept has and which potential improvements to the solution concept should be focused on.

The validation takes place in two phases. First, the AI workflow is provided with dummy documents and information and tested to determine whether the workflow and the interfaces function smoothly and without errors. If the test with the so-called dummy file is successful, the algorithm is applied and tested based on real project documentation from a tier 1 service provider company in the German automotive industry that develops embedded software for electronic car control units. The results will be presented in further publications.

CONCLUSIONS

The increasing complexity at the organizational level as well as the increasing complexity of products is challenging companies and their industrial projects. On the one hand, the companies should react even faster in planning the projects and making decisions regarding resources, competencies, time, and money to maintain the market position against the competition. But, on the other hand, industrial projects cannot be easily estimated prospectively due to their complexity. This situation leads to industrial projects being delayed or failing and this means consequential and poor-quality costs and damage to the company's image. To overcome this situation, the department "Product Safety and Quality Engineering" is developing a systematic approach for competency-based project planning of industrial projects, which uses modern IT-based solutions from the field of artificial intelligence (AI) for support. For this purpose, the problem was first analyzed and described in this paper. Subsequently, comprehensive literature research was made to be able to analyze the scientific gap. Based on the literature five topics followed by four Subgoals were defined and a solution concept was proposed to cover the subgoals. Based on the subgoals, the concept was then broken down into four work packages to ensure a transparent and systematic approach. In WP1 and WP2, the algorithm will be trained with manually structured data sets, which also are provided with problem field-related labels. In this way, the algorithm collects knowledge from previous company projects and can distinguish which projects led to success or failure based on which type of planning. Based on this, the algorithm in WP3 can receive additional information about a new project from the project manager via the input mask on the front-end of the designed AI workflow, access the company's existing information database, and provide a prediction about the upcoming project to support the project manager regarding the competency-based resource planning. In WP4, a validation will be performed based on the real data from the German industry to identify the potential improvements and weaknesses of the AI-based workflow.

REFERENCES

Adolf, M. (2017) Komplexität als Herausforderung der Kommunikationswissenschaft: von Landkarten, Strategien und Fallen. *M&K Medien & Kommunikationswissenschaft*, 65(3), 500–516. Available from: https://doi.org/10.5771/1615-634X-2017-3-500.

Arunthavanathan, A., Shanmugathasan, S., Ratnavel, S., Thiyagarajah, V., Perera, I. & Meedeniya, D. et al. (2016) Support for traceability management of software artefacts using Natural Language Processing. In: MERCon (Ed.) *2016 Moratuwa Engineering Research Conference (MERCon), 2016 Moratuwa Engineering Research Conference (MERCon)*, Moratuwa, pp. 18–23.

Buxmann, P. (Ed.) (2019) *Künstliche Intelligenz: Mit Algorithmen zum wirtschaftlichen Erfolg*. Springer Gabler: Berlin, [Germany].

Chen, J.-H., Su, M.-C., Azzizi, V.T., Wang, T.-K. & Lin, W.-J. (2021) Smart Project Management: Interactive Platform Using Natural Language Processing Technology. *Applied Sciences*, 11(4), 1597. Available from: https://doi.org/10.3390/app11041597.

Farid, W.M. (2012) The NORMAP Methodology: Lightweight Engineering of Non-functional Requirements for Agile Processes. In: APEC (Ed.) *2012 19th Asia-Pacific Software Engineering Conference, 2012 19th Asia-Pacific Software Engineering Conference*, Hong Kong, China, pp. 322–325.

Farid, W.M. & Mitropoulos, F.J. (2012) NORMATIC: A visual tool for modeling Non-Functional Requirements in agile processes. In: IEEE Southeastcon (Ed.) *2012 Proceedings of IEEE Southeastcon, 2012 Proceedings of IEEE Southeastcon*, Orlando, USA, pp. 1–8.

Gembrys, S.-N. & Herrmann, J. (2009) *Qualitätsmanagement*, 2nd edition. Haufe: Planegg/München.

Grimm, K. (2003) Software technology in an automotive company - major challenges. In: ICSE (Ed.) *25th International Conference on Software Engineering, ICSE 2003, 3-10 May 2003, Portland, Oregon, USA: Proceedings, 25th International Conference on Software Engineering, 2003. Proceedings,* 5/10/2003 - 5/10/2003, Portland, OR, USA. IEEE: Los Alamitos, Calif., pp. 498–503.

Harrington, H.J. (1987) *Poor-quality cost*. CRC Press: Boca Raton.

Hartwig, A. (2010) *Untersuchung und Bewertung ausgewählter Qualitätsmanagementmethoden, die Einordnung in Qualitätsmanagementsysteme und praktische Anwendung*. Diplom.de: Hamburg.

Hussain, I., Kosseim, L. & Ormandjieva, O. (2013) Approximation of COSMIC functional size to support early effort estimation in Agile. *Data & Knowledge Engineering*, 85, 2–14. Available from: https://doi.org/10.1016/j.datak.2012.06.005.

IONESCU, V.-S., DEMIAN, H. & CZIBULA, I.-G. (2017) Natural Language Processing and Machine Learning Methods for Software Development Effort Estimation. *Studies in Informatics and Control*, 26(2). Available from: https://doi.org/10.24846/v26i2y201710.

Kapici, S. (2005) *Ein stochastisches Risikomodell für komplexe Projekte: Dissertation*. angenommen durch die Fakultät für Informatik der Otto-von-Guericke-Universität Magdeburg. Available from: https://opendata.uni-halle.de/bitstream/1981185920/10673/1/senkapici.pdf [Accessed 12 March 2020].

Khare, A., Stewart, B. & Schatz, R. (Eds.) (2017) *Phantom Ex Machina: Digital Disruption's Role in Business Model Transformation*. Springer International Publishing: Cham, s.l.

Kumar, E. (2011) *Natural language processing*. I.K. International Publishing House: New Delhi.

Kuster, J., Bachmann, C. & Huber, E. (2019) *Handbuch Projektmanagement: Agil - klassisch - hybrid*, 4th edition. Springer Gabler: Berlin.

Lange, S. (2015) *Komplexität im Projektmanagement: Methoden und Fallbeispiele für erfolgreiche Projekte*.

Lucassen, G., Dalpiaz, F., van der Werf, J.M.E.M. & Brinkkemper, S. (2016) Improving agile requirements: the Quality User Story framework and tool. *Requirements Engineering*, 21(3), 383–403. Available from: https://doi.org/10.1007/s00766-016-0250-x.

Luhmann, N. (2005) Komplexität. In: Luhmann, N. (Ed.) *Aufsätze zur Theorie der Gesellschaft,* 5th edition. VS Verl. für Sozialwiss: Wiesbaden, pp. 255–276.

Mistler, M. (2021) *Entwicklung eines Vorgehenskonzeptes zum modellbasierten agilen Anforderungsmanagement (Requirements Engineering und Requirements Management) für Organisationen – REMOt*. Dissertation, Wuppertal, Bergische Universität Wuppertal. Available from: https://doi.org/10.25926/ZFTC-T276.

Rane, P.P. (2017) *Automatic Generation of Test Cases for Agile using Natural Language Processing: Automatic Generation of Test Cases for Agile using Natural Language Processing*. Virginia Tech.

S.Phabmixay, C., Rodríguez-Escudero, A.I. & Rodríguez-Pinto, J. (2018) Organizational antecedents to designing a comprehensive complaint management system. *Journal of Management & Organization*, 9, 1–26. Available from: https://doi.org/10.1017/jmo.2018.73.

Schatz, A., Schöllhammer, O. & Jäger, J. (2014) Ansatz zum Umgang mit Komplexität in Unternehmen. *Controlling*, 26(12), 686–693. Available from: https://doi.org/10.15358/0935-0381_2014_12_686.

Schlueter, N., Winzer, P., Ansari, A., Bielefeld, O., Dransfeld, H. & Heinrichsmeyer, M. (2018) KAUSAL: A New Methodological Approach for Model Based Analysis of Complex Failure Chains by Example of an Electromobility Concept. In: IEEE (Ed.) *2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC), 2018 IEEE International Conference on Systems, Man, and Cybernetics (SMC),* 7-10 October, Miyazaki, Japan. IEEE, pp. 947–952.

Sharma, S., Kumar, D. & Fayad, M.E. (2019) Simplified Agile Software Project Selection Model Using Natural Language Processing Based Upon Agile Team Skills. In: ICCIKE (Ed.) *2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE), 2019 International Conference on Computational Intelligence and Knowledge Economy (ICCIKE)*, Dubai, UAE, pp. 264–269.

Sundararajan, M., Srikrishnan, P. & Nayak, K. (2018) Requirements Complexity Definition and Classification using Natural Language Processing. In: ICI3I (Ed.) *2018 3rd International Conference on Contemporary Computing and Informatics (IC3I), 2018 3rd International Conference on Contemporary Computing and Informatics (IC3I)*, Gurgaon, Indien, pp. 76–80.

Thiebes, F. & Plankert, N. (2014) Umgang mit Komplexität in der Produktentwicklung – Komplexitätsbeherrschung durch Variantenmanagement. In: Schoeneberg, K.-P. (Ed.) *Komplexitätsmanagement in Unternehmen: Herausforderungen im Umgang mit Dynamik, Unsicherheit und Komplexität meistern.* Springer Gabler: Wiesbaden, pp. 165–185.

Vöcking, B. (Ed.) (2008) *Taschenbuch der Algorithmen*. Springer: Berlin, Heidelberg.

Wess, S. (2019) Mit Künstlicher Intelligenz immer die richtigen Entscheidungen treffen. In: Buxmann, P. (Ed.) *Künstliche Intelligenz: Mit Algorithmen zum wirtschaftlichen Erfolg.* Springer Gabler: Berlin, [Germany], pp. 143–160.

Wilson, S.A. & Perumal, A. (2010) *Waging war on complexity costs: Reshape your cost structure, free up cash flows, and boost productivity by attacking process, product, and organizational complexity // Reshape your cost structure, free up cash flows, and boost productivity by attacking process, product and organizational complexity*. McGraw-Hill: New York.

Winzer, P. (2016) *Generic systems engineering: Ein methodischer ansatz zur komplexitätsbewältigung*, 2nd edition. Springer Vieweg: Berlin, [Germany], Heidelberg, [Germany].

Zichler, K. & Helke, S. (2017) Ontologiebasierte Abhängigkeitsanalyse im Projektlastenheft. In: Dencker, P., Klenk, H., Keller, H.B. & Plödereder, E. (Eds.) *Automotive - Safety & Security 2017: Sicherheit und Zuverlässigkeit für automobile Informationstechnik : 30.-31. Mai 2017 Stuttgart, Germany.* Gesellschaft für Informatik e.V. (GI): Bonn, pp. 121–134.

Zwirn, F. (2013) *Analyse und Auswertung von gewichteten Anforderungen in technischen Spezifikationen*.

Quality 4.0: An exploratory literature review and avenues for future research

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STRUCTURED ABSTRACT

Purpose - This paper presents the results of an exploratory literature review on the topic of Quality 4.0, conducted with the aim of better understanding what different authors and studies advocate becoming, or already being, Quality 4.0. It also tries to identify avenues for future research in quality management.

Design/methodology/approach - The Scopus platform was used to search for the documents, using the research equation: [("Quality 4.0" OR "Quality Management") AND ("Industry 4.0")]. Documents were filtered for date range (2019 to 2021) and for type (articles and conference proceedings). From a total of 148 documents identified for abstract reading, 50 were subject to full reading and exploratory content analysis.

Findings - The analysed documents essentially provide theoretical discussions and recommendations on what is or should be Quality 4.0. These were identified and grouped into six categories: Industry 4.0 and the Rise of a New Approach to Quality; Motivations, Readiness Factors and Barriers to a Quality 4.0 Approach; Quality Restructuring; Digital Quality Management Systems; Combination of Quality Tools and Lean Methodologies; and Quality 4.0 Professionals.

Research limitations/implications - Studies reporting what is actually occurring, showing how quality is managed in organisations already situated in the Industry 4.0 paradigm, are still hard to find. Questions regarding actual practices, methodologies and tools being used in Quality 4.0 approaches still need to be answered, which calls for further empirical research in the area.

Originality/value – The value of this work resides in its broad look at how quality management is changing in response to the affirmation of the Industry 4.0 paradigm.

Keywords: Quality 4.0; Industry 4.0; Systematic Literature Review

Paper type: Research paper

INTRODUCTION

Before clarifying the concept of Quality 4.0, it is necessary to understand the concept of Industry 4.0. Given the rapid evolution of technology in recent years, words such as speed or data management are increasingly present in the business world. At this moment, the industry is witnessing a new industrial revolution, also known as Industry 4.0 (I4.0). This fourth industrial revolution, which originated in Germany in 2011, brings profound changes to industry and society in general. The fourth industrial revolution is the revolution in production processes motivated by the integration of new technologies.

This new industrial reality has profound implications not only in terms of the way companies are organized and managed, but also with regard to the functions of their employees. In particular, it is expected that Industry 4.0 will also imply a transformation in terms of quality management. The concept of quality in this new era must be based on disruptive thinking to achieve evolution in the business world, especially with regard to the digital revolution (Zonnenshain & Kenett, 2020). According to Lee et al. (2019), there is a change in the control method of "preventive maintenance and quality management procedures." Previously these were controlled by people, but with the arrival of the fourth industrial revolution, these prevention processes are being controlled by new technologies, such as Information Technologies (IT), Big Data, and Artificial Intelligence (AI). However, this new reality brings with it relevant challenges for professionals in the area, since there is a need to adapt to these new technologies, to new data processing and analysis techniques, as well as to the entrepreneurship ecosystem of this fourth industrial revolution (Zonnenshain & Kenett, 2020). Since there is a set of innovative technologies, such as AI, that fuel the digital transformation, it is also necessary to have a restructuring of international standards, which is why the development of some new standards is already underway, such as, for example, ISO/IEC CD 42001 and ISO/IEC CD 23894 (ISO, 2022). Industry 4.0 brings not only a technological revolution in the area of quality but also the development of a new culture of quality, that is, there is a need to restructure the traditional concepts of quality so that they adapt to this new industry paradigm (Chiarini, 2020).

A systematic review of recent literature on quality management, prepared by Chiarini (2020), found that, currently, there is still little research related to the integration of quality management tools and principles in Industry 4.0. As such this is an area with some research potential, namely with regard to the characterization of the concept of Quality 4.0, including its main characteristics, but also the challenges that this new logic of quality represents for organizations.

Thus, the questions to be developed in this research paper can be formulated as follows:

- How is quality management changing to fit the needs and requirements of Industry 4.0?
- Can we really talk about a new approach to quality management today, the so-called Quality 4.0? What are its main characteristics?

- Are companies prepared to implement this new approach to quality management?
- What are the skills and knowledge employees in the quality area will need to be prepared to work under a Quality 4.0 approach?

The paper presents the results of an exploratory literature review conducted with the aim of trying to answer these questions by better understanding the evolution of quality management in the context of the affirmation of the Industry 4.0. In particular, we seek to understand what different authors and studies advocate becoming, or already being, Quality 4.0, and how companies and quality professionals are evolving to work within this new approach to quality management.

RESEARCH METHODOLOGY

The Scopus platform was used to search for documents addressing the topic of Quality 4.0, using the following research equation: [("Quality 4.0" OR "Quality Management") AND ("Industry 4.0")]. Documents were filtered for date range, being selected those from 2019 to 2021, and for type (only articles and conference proceedings). A total of 148 documents were identified for abstract reading, which afterward led to the exclusion of those only focused on Industry 4.0, those that although related to the theme of quality management did not focus on Quality 4.0, as well as those whose access implied payment. Thus, 50 documents were finally identified for full reading and exploratory content analysis. The exploratory literature review was prepared as presented in Figure 1.

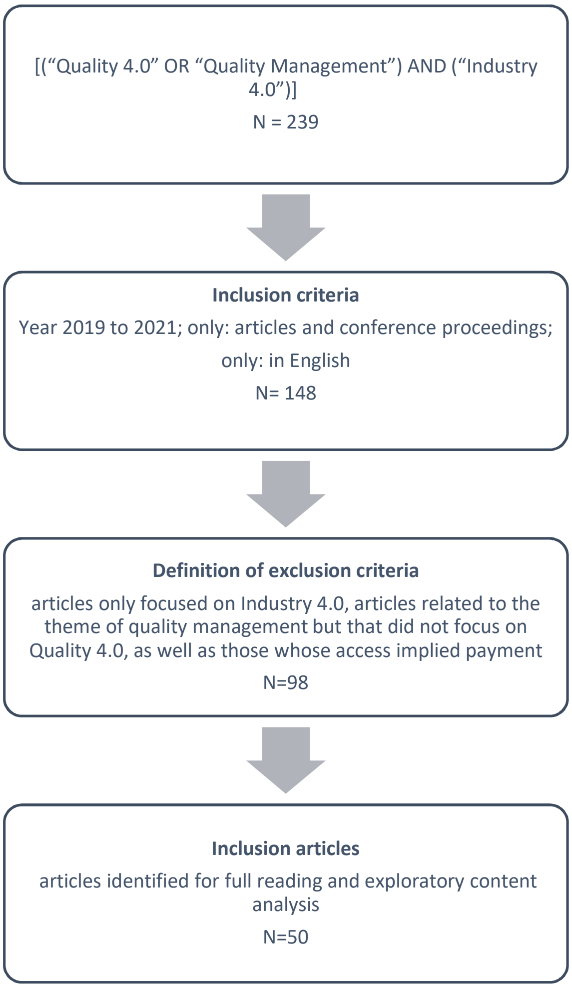

Figure 1. Research strategy of the systematic literature review

RESULTS

The content analysis of the 50 documents retained in the systematic literature review research strategy, allowed to identify a set of topics that can be grouped into the following categories: Industry 4.0 and the Rise of a New Approach to Quality; Quality Restructuring; Motivations, Readiness Factors and Barriers to a Quality 4.0 Approach; Digital Quality Management Systems; Combination of Quality Tools and Lean Methodologies; and Quality 4.0 Professionals. In what follows, a description is presented of these categories, based on which some answers to the research questions initially raised will be tentatively put forward.

Industry 4.0 and the Rise of a New Approach to Quality

15 out of the 50 analysed documents discuss the emergence of the Industry 4.0 paradigm and the rise of a new approach to quality – the so-called Quality 4.0 – within it.

The focus of companies is changing and the attention that was previously directed to the product is, in this new era, being directed to data; therefore, quality combined with Industry 4.0 can now be considered a data-oriented discipline (Chiarini, 2020). New technologies and digital processes related to Big Data and Artificial Intelligence (AI) will radically change the way companies will compete and remain competitive (Petcharit et al., 2020). Consideration should be given to trends occurring in international and domestic markets, as well as to reducing financial costs, and preserving and entering into new contracts in developing and particularly sensitive markets (Solod et al., 2020).

The characteristics of a smart factory are the production of smart and personalized products achieved through networks, fundamentally based on Information Technologies (IT). Concepts such as Industry 4.0, machine vision system, image processing are part of the set of new technologies that are used for complex contours and fast production (Subramanian et al., 2019).

Today, organizations offer the supplier the opportunity to engage with the processes of the companies they supply to. This involvement gives you access to first-hand knowledge about your customers' needs and, indirectly, your competitors' capabilities (Cerezo-Narváez et al., 2019). The emergence of the Industry 4.0 concept brought not only new requirements in product manufacturing, but also changing requirements for a product quality monitoring system (Pipiay et al., 2021). Smart sensors, automation and Big Data can support Statistical Process Control (SPC) or Six Sigma at the process level or provide data for high-level Total Quality Management (TQM) and business excellence models (Fonseca et al., 2021). This new era of quality is based on traditional quality tools but also considers connectivity, intelligence and automation, in order to improve performance and data-driven decision making in an end-to-end scenario, involving all stakeholders and providing visibility and transparency. Quality 4.0 is not just a definition, but also a real model (Chiarini, 2020).

Traditional quality concepts must absorb changes and prepare for new challenges. According to Črešnar et al. (2020), traditional tools such as the use of Six Sigma, TQM, radiofrequency identification, balanced scorecard, rapid prototyping, customer segmentation, mission and vision statements, digital transformation and Total Productive Maintenance (Wszołek et al., 2020), should have a predominant role in the strategic transformation of the organization and in the implementation of Industry 4.0. Sader et al. (2019), suggest that Industry 4.0 will allow organizations to improve customer satisfaction through quality improvement and delivery of differentiated products and services, due to intensive quality control and quality assurance practices. In advanced industry systems, there is a great interaction between intelligent design, advanced and industrial metrology and technological developments. Special points of interest are the areas of quality, environmental and energy management, automation, high precision, high efficiency, precision manufacturing and metrology (Durakbasa & Bas, 2019). According to Bauer et al. (2020), one of the technologies that is at the base of Industry 4.0 is Augmented Reality (AR), which plays an important role in aiding manual assembly. This technology can also support monitoring features that comply with TQM requirements, thereby minimizing errors and maximizing quality. However, AR requires a deep and detailed analysis of each case so that the final solution is adequately suited to the specific case (cost, functionalities, etc.) (Bauer et al., 2021).

In summary, although this new era of quality is still based on traditional quality tools, it also considers connectivity, intelligence and automation in order to improve performance and data-driven decision making. A restructuring of quality management is then necessary, with a view to integrating new technologies, such as Big Data, AI, AR, with traditional quality models and approaches.

Quality Restructuring

15 out of the 50 documents analysed address the need for a restructuring of Quality. In an attempt to respond to the trend of Industry 4.0, the quality area is undergoing a phase of change and evolution in order to help establish the role and implications of quality in this new industrial era.

The focus of Quality 4.0 is on the quality of modern products and, more specifically, how to ensure that modern technologies produce quality products. The culture of quality in this new era of digitalization focuses on quality as a strategic advantage (Durana et al., 2019). In a short time, it will be feasible to use quality management in Industry 4.0 (Goecks et al., 2020). However, traditional quality management tools as well as quality principles may not entirely fit the requirements of modern production systems (Mareček-Kolibiský & Kučerová, 2021).

In this new industrial era, the emergence of the Internet of Things (IoT) and Wireless Sensor Networks (WSN) significantly affects modern industry in all aspects, from logistics to quality control (Najmi et al., 2021). The combination of Big Data, IoT, and analytics makes it possible to solve problems using real-time data, eliminating the bias caused by using historical data from the production floor (Vo et al., 2020). Real-time monitoring and optimization of production and logistics processes significantly improves the efficiency of production systems (Rácz-Szabó et al., 2020).

According to Zonnenshain and Kenett (2020), quality evolved through six stages, namely, product quality, process quality, service quality, management quality, design quality and information quality. The latter is fundamentally linked to the development of enterprise resource planning (ERP) systems and the manufacturing execution system (MES) software. According to Fatima et al. (2020), the MES system is a key component for optimized production planning in this new industrial era, acting as a bridge between various shop floor systems. However, despite the alerts and results provided by the system for supporting decision, it still does not incorporate decision support tools that allow the implementation of adaptive delivery strategies that respond to unforeseen events, in order to better respond to changes in dynamic environments. To turn this combination into a reality, it is necessary to face the barriers imposed by the lack of integration of the information produced throughout the life of the product, by the different computer systems (Riaño et al., 2019).

In a survey carried out by Nedelko, (2021), it was found that the most prominent tools for integrating quality management in this new industrial era are Six Sigma management, rapid prototyping, outsourcing, customer relationship management, knowledge management, core competencies and strategic planning.

According to Montanari et al. (2021), there are several tools that can be used to increase internal efficiency. Among them the following stand out: i) Statistical Process Control, which includes the use of statistical methods and metrics to monitor and control the quality of a process; and ii) the Six Sigma method, to ensure that products meet customer requirements and have zero defects.

Predictive analytics can also help increase the efficiency of quality management in this new era of industry. Predictive analytics tools such as Data Mining or Image Data Mining (Trinks & Felden., 2019), AI and Machine Learning (ML) (Dovleac et al., 2022) can be critical in this new industrial era. However, there is a wide variety of technologies that are currently used in organizations that will need to be updated in the future. (Vasiliev et al., 2020)

Also, in terms of service quality, there needs to be a change in thinking about the integration of new technologies. Service quality is the key to creating business differentiation, as well as raising a higher level of competitiveness in the market. To improve quality of service, technology must be taken into account at all levels, in order to increase consumer satisfaction. (Charernnit 2020, Popkova & Giyazov 2021)

Motivations, Readiness Factors and Barriers to a Quality 4.0 Approach

4 out of the 50 reviewed documents highlight as the main motivations leading industries to adopt a Quality 4.0 approach (e.g. Sony et al., 2021) the need to treat and analyse big data, the search for improved customer satisfaction, productivity improvement, and long-term cost and time savings.

According to Bhat et al. (2021), top management motivation and awareness, the concept of big data, engineering knowledge, comprehensive simulation-based process analysis and external technical guidance are part of the set of critical success factors for adopting a Quality 4.0 approach. To Chau et al. (2021), customer focus is the strongest factor for quality management improvement. Indeed, customer satisfaction and involvement, as well as communication with customers are crucial aspects for effective quality management. In a study on the readiness factors for Industry 4.0, Tasmin et al. (2020), state that there is a strong relationship between the readiness factors for Industry 4.0, namely

Applied Technology, the ERP, the IoT and the Cyber-Physical System (CPS) and quality performance. A simple tool to analyze the readiness factors of companies for Industry 4.0 is the EFQM 2020 model (Turisová et al., 2021).

On the other hand, 2 out of the 50 documents point to existent barriers regarding the adoption of Quality 4.0, such as the initial costs associated with its implementation, the complexity of calculating the return on investment (ROI), the lack of resources, the lack of knowledge about what Quality 4.0 is and what practices, methodologies and/or tools support it or the existence of an unfavourable organizational culture (Sony et al., 2021). The potential decrease in employability, the need to improve employee skills, issues related to security and privacy, and errors in device operation are also identified as barriers to the adoption of Quality 4.0 (Kovrigin & Vasiliev, 2020).

Digital Quality Management Systems

The analysed documents (3 out of 50) also highlight that Quality 4.0 will be based on digital quality management systems, which implies the emergence of a common area of work for specialists in quality management and specialists in information management systems and technologies. Vasiliev et al. (2020) refer that a digital quality management system must have the ability to receive, process and analyse information and data about processes in real time and propose management decisions to company leaders, develop and propose management forms to solve and respond to changes in the company's external environmental conditions, optimize the company's functional and organizational structures, the number of departments, personnel and managers based on the strategic development decisions taken by the administration and, lastly, guarantee the quality control of production processes and finished products, as well as the management of inconsistencies. Quality management systems are moving towards sustainability, big data and applied technological innovations (Minglana et al., 2022).

In this new industrial era, a new concept is also born, called Virtual Quality Management. This concept is based on simulation studies that are efficiently implemented with the sole purpose of "generating resilient knowledge and dimensioning quality techniques" that can be applied to products or processes before their physical existence. (Weckenmann et al., 2019 p. 6). The combination of “simulation” and “virtual reality” allows operators to virtually interact with the manufacturing process, which in turn enables virtual control and even virtual inspection of the manufacturing flow. (Weckenmann et al., 2019 p. 7). Another key factor of Virtual Quality Management is communication. The development of virtual channels (supported by the internet) has brought several advantages, namely, the improvement of communication between humans or even with machines (Weckenmann et al., 2019).

Combination of Quality Tools and Lean Methodologies

According to 8 of the 50 analysed documents, the combination of quality tools with lean methodologies will also be a characteristic of organizations that work under the Industry 4.0 paradigm (Charrua-Santos et al., 2020, Siphoro et al., 2020; Tissir et al. , 2020, Yadav et al., 2021, Bhat et al., 2021). To Charrua-Santos et al. (2020), since lean methodologies have been widely adopted by companies in recent decades, it would not be appropriate to consider implementing Industry 4.0 technologies without considering their integration. However, and according to these authors research, the implementation of lean methodologies is not being carried out uniformly, which indicates that more studies on this topic still need to be developed. Integrating the use of traditional lean and quality methodologies and tools into Industry 4.0, such as 5S, JIT or Jidoka, can substantially improve an organization's results, both in terms of quality and productivity (Tissir et al., 2020).

Industry 4.0 solutions, such as digitization, along with lean production methodologies can support quality control operations (Garcia-garcia et al., 2021). Design Of Experiments, Taguchi – Gray Relational Analysis, simulation and robust control system tools are the necessary technical tools that allow combining Lean Six Sigma and Industry 4.0 (Bhat et al., 2021). When implementing the ISO 9001:2015, the organizations can use the digital Standard Operating Procedure (SOP) in order to minimize waste and avoid variations during production (Siphoro et al., 2020). According to Yadav et al. (2021), the future belongs to technologies, having the authors verified that the use of new technologies in an Industry 4.0 context can substantially improve the application of Lean Six Sigma methodologies. Lean Six Sigma methodologies and emerging Information and Communication Technologies have a significant impact on organizational performance (Yadav et al., 2020).

Thus, it appears that the lean production systems are only partially prepared to integrate Industry 4.0, that is this methodology should be updated in order to better address this new industrial paradigm (Saxby et al., 2020). A better understanding of the meaning of Industry 4.0 technologies can support proactive initiatives that can potentially converge with previous efforts to implement lean production practices (Tortorella et al., 2019).

Quality 4.0 Professionals

Quality professionals will have to adapt to this new industrial era. 5 out of the 50 analysed documents refer to this and highlight the knowledge and skills, both hard and soft, that these professionals should master. They will have to be able to interpret large amounts of data to make decisions, use data and new tools of AR to identify the sources of problems and to access reliable sources of learning. In terms of personal skills, the ability to adapt to frequent changes will be crucial in this new era. They may also have to learn how to use new tools, such as the WEKA Data Mining software, to increase efficiency in problem solving (Kannan & Garad, 2021). Production decision making, social interaction, cross-functional understanding and technological expertise are factors that also play a crucial role in the integration of this new industrial era (Bhat et al., 2021). This will require the next generations of professionals to develop digital skills and build access to lifelong learning (Dovleac et al., 2022).

Quality 4.0 professionals must have skills such as creative thinking, leadership, teamworking and communication. In addition, they must be aware of new technologies, that is, cyber-physical production systems and combine this with the best quality management practices, where their decisions will be based on Big Data. They must have the ability to adapt to changes and challenges that arise. In addition, they should acquire knowledge of new technologies as they emerge (Santos et al., 2021).

Both IT and production knowledge will be important in this new paradigm. The fact is that it is not just educational content that must change, but also skill development methods must be at the forefront of the moment to meet the needs of a new generation of employee (Savelyeva & Shumakova, 2020). The new digital technologies created and developed in Industry 4.0, can and should be adapted to the needs and specificities of universities' activities in the near future, namely AI, VR and alternative, high-speed Internet (industrial), data processing technologies, Big Data, Iot and blockchain technologies (Bratukhina et al., 2019, Lysova et al., 2019).

CONCLUSION

The exploratory literature review carried out allowed for a first analysis of the influence of Industry 4.0 in the area of Quality. In response to the first and second questions, after this exploratory review, it appears that Industry 4.0 not only brings a technological revolution in the area of quality, but also the development of a new culture of quality (Chiarini, 2020). This new paradigm of Quality must be increasingly based on the collection and processing of data, using modelling and simulation techniques, which allow forecasting. Quality management tests will not be done on a separate metrology segment, but on the real-time manufacturing line (Najmi et al., 2021). One can speak of a new era of quality, which refers to the digitization of TQM and its impact on technology, processes and quality people. This new era of quality is based on traditional quality tools, but also considers connectivity, intelligence and automation in order to improve performance and data-driven decision making in an end-to-end scenario, involving all stakeholders and providing visibility and transparency (Chiarini, 2020).

As an answer to the third question, it appears that companies are not yet prepared to implement Quality 4.0, since there are several tools that are not fully prepared to integrate Industry 4.0 (Vasiliev et al., 2020). The Lean methodology should also be updated in order to better address the topic of Industry 4.0 (Saxby et al., 2020).

Answering the last question, quality professionals will need to be able to interpret and use large amounts of data. They will also have to learn how to use new tools, such as AR or WEKA Data Mining software, for greater efficiency in problem solving (Kannan & Garad, 2021). At the level of personal skills, the ability to adapt to frequent changes, production decision making, social interaction, multifunctional understanding and technological knowledge are factors that also play a crucial role for quality professionals in this new industrial era (Bhat et al., 2021).

It should be noted that this is still a relatively recent topic and essentially anchored in theoretical discussions and recommendations about what should, or could be, Quality 4.0. There is a lack of studies that report the reality on the ground, that is, that show how quality is effectively managed in organizations located in the Industry 4.0 paradigm. What quality practices, methodologies and tools are used? What is the maturity level regarding the digitization of quality management systems? Who are the current professionals responsible for managing quality and what are their skills? For these and other questions, the literature does not yet provide answers, so there seems to be room for and need for more research in this area.

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REFERENCES

Bauer, R. D., Santa, E. De, Udesc, C., Santa, E. De, Udesc, C., Hounsell, S., Santa, E. De, Udesc, C., Tavares, A., Santa, E. De, & Udesc, C. (2020). *Manual PCB assembly using Augmented Reality towards Total Quality*. 189–198. https://doi.org/10.1109/SVR51698.2020.00040

Bauer, R. D., Watambak, T. L., Agati, S. S., Da Silva Hounsell, M., & Da Silva, A. T. (2021). Development and Evaluation of a PCB's Manual Assembly system using Augmented Reality and Total Quality. *ACM International Conference Proceeding Series*, 24–32. https://doi.org/10.1145/3488162.3488231

Bhat, V. S., Bhat, S., & Gijo, E. V. (2021). Simulation-based lean six sigma for Industry 4.0: an action research in the process industry. *International Journal of Quality and Reliability Management*, *38*(5), 1215–1245. https://doi.org/10.1108/IJQRM-05-2020-0167

Bratukhina, E. A., Sozinova, A. A., & Matushkina, Y. N. (2019). Digital modernization of the region's educational market and its influence on the quality of education. *International Journal for Quality Research*, *14*(1), 253–270.

Cerezo-Narváez, A., García-Jurado, D., González-Cruz, M. C., Pastor-Fernández, A., Otero-Mateo, M., & Ballesteros-Pérez, P. (2019). Standardizing innovation management: An opportunity for SMEs in the aerospace industry. In *Processes* (Vol. 7, Issue 5). https://doi.org/10.3390/pr7050282

Charernnit, K. (2020). Educational and digital tools as factors of service quality increase in Thailand 4.0 era (the case of Suvarnabhumi Airport, Bangkok). *E3S Web of Conferences*, *210*. https://doi.org/10.1051/e3sconf/202021022009

Charrua-Santos, F., Santos, B. P., Enrique, D. V., Alberto, A., Bibete, H., Osório, G. J., & Lima, T. M. (2020). An Overview of Lean Production and Industry 4.0 in Different Context. *ICITM 2020 - 2020 9th International Conference on Industrial Technology and Management*, 69–72. https://doi.org/10.1109/ICITM48982.2020.9080386

Chau, K. Y., Tang, Y. M., Liu, X., Ip, Y. K., & Tao, Y. (2021). Investigation of critical success factors for improving supply chain quality management in manufacturing. *Enterprise Information Systems*, *15*(10), 1418–1437. https://doi.org/10.1080/17517575.2021.1880642

Chiarini, A. (2020). Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research. *TQM Journal*, *32*(4), 603–616. https://doi.org/10.1108/TQM-04-2020-0082

Črešnar, R., Potočan, V., & Nedelko, Z. (2020). Management Tools : Empirical Investigations in. *Sensors*, *20*(3469).

Dovleac, R., Ionica, A., & Leba, M. (2022). Knowledge Management Embedded in Agile Methodology for Quality 4.0. *2021 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 1260–1264. https://doi.org/10.1109/ieem50564.2021.9673045

Durakbasa, N. M., & Bas, G. (2019). From nano-to pico-to feinto-: Future challenges for cost-oriented manufacturing. *IFAC-PapersOnLine*, *52*(25), 382–386. https://doi.org/10.1016/j.ifacol.2019.12.557

Durana, P., Kral, P., Stehel, V., Lazaroiu, G., & Sroka, W. (2019). Quality Culture of Manufacturing Enterprises : *Social Sciences*, *8*(4), 124.

Fatima, B., Sarah, A., & Driss, A. (2020). The Manufacturing Executing System instead of ERP as shop floor management. *2020 13th International Colloquium of Logistics and Supply Chain Management, LOGISTIQUA 2020*. https://doi.org/10.1109/LOGISTIQUA49782.2020.9353907

Fonseca, L., Amaral, A., & Oliveira, J. (2021). Quality 4.0: The efqm 2020 model and industry 4.0 relationships and implications. *Sustainability (Switzerland)*, *13*(6). https://doi.org/10.3390/su13063107

Garcia-garcia, G., Coulthard, G., Jagtap, S., Afy-shararah, M., Patsavellas, J., & Salonitis, K. (2021). *Business Process Re-Engineering to Digitalise Quality Control Checks for Reducing Physical Waste and Resource Use in a Food Company*.

Goecks, L. S., dos Santosa, A. A., & Korzenowski, A. L. (2020). Decision-making trends in quality management: A literature review about industry 4.0. *Production*, *30*. https://doi.org/10.1590/0103-6513.20190086

ISO/IEC CD 42001.2 Information Technology — Artificial intelligence — Management system. Status available at: https://www.iso.org/standard/81230.html

ISO/IEC DIS 23894 Information technology — Artificial intelligence — Risk management. Status available at: https://www.iso.org/standard/77304.html

Kannan, K. S. P. N., & Garad, A. (2021). Competencies of quality professionals in the era of industry 4.0: a case study of electronics manufacturer from Malaysia. *International Journal of Quality and Reliability Management*, *38*(3), 839–871. https://doi.org/10.1108/IJQRM-04-2019-0124

Kovrigin, E. A., & Vasiliev, V. A. (2020). Barriers in the integration of moderndigital technologies in the system of quality management of enterprises of the aerospace industry. *Proceedings of the 2020 IEEE International Conference "Quality Management, Transport and Information Security, Information Technologies", IT and QM and IS 2020*, 331–335. https://doi.org/10.1109/ITQMIS51053.2020.9322960

Lee, S. M., Lee, D., & Kim, Y. S. (2019). The quality management ecosystem for predictive maintenance in the Industry 4.0 era. *International Journal of Quality Innovation*, *5*(1). https://doi.org/10.1186/s40887-019-0029-5

Lysova, E. A., Lapteva, I. P., & Malysheva, N. V. (2019). Marketing management of education quality in the process of university reorganization in industry 4.0: goals of application. *International Journal for Quality Research* 14(2) 369–386.

Mareček-Kolibiský, M., & Kučerová, M. (2021). Application of Quality Management in Business Practice in the Context of Industry 4.0. *METAL 2021 - 30th Anniversary International Conference on Metallurgy and Materials, Conference Proceedings*, 1274–1279. https://doi.org/10.37904/metal.2021.4280

Minglana, J., Tobias, R. R., & Roxas, R. E. (2022). Artificial Intelligence Applications in Quality

Management System: A Bibliometric Study. *TENCON 2021 - 2021 IEEE Region 10 Conference (TENCON)*, 947–952. https://doi.org/10.1109/tencon54134.2021.9707340

Montanari, R., Volpi, A., Tebaldi, L., Di, G., Bottani, E., Montanari, R., Volpi, A., Tebaldi, L., & Di, G. (2021). ScienceDirect Statistical Statistical Process Control of assembly lines in a manufacturing plant : Process Capability assessment plant : Process Capability assessment. *Procedia Computer Science*, *180*(2019), 1024–1033. https://doi.org/10.1016/j.procs.2021.01.353

Najmi, G., El, O., Isc, A., & Charrier, Q. (2021). Integration of the quality control process into a 4 . 0 production system. *2021 International Conference on Electrical, Computer, Communications and Mechatronics Engineering (ICECCME)*, *October*, 1–6. https://doi.org/10.1109/ICECCME52200.2021.9591037

Nedelko, Z. (2021). What drives the usage of management tools supporting industry 4.0 in organizations? *Sensors*, *21*(10). https://doi.org/10.3390/s21103512

Petcharit, A., Sornsaruht, P., & Pimdee, P. (2020). An analysis of total quality management (TQM) within the thai auto parts sector. *International Journal of Online and Biomedical Engineering*, *16*(2), 131–145. https://doi.org/10.3991/ijoe.v16i02.11917

Pipiay, G. T., Chernenkaya, L. V., & Mager, V. E. (2021). Quality Indicators of Instrumentation Products According to the “quality 4.0” Concept. *Proceedings of the 2021 IEEE Conference of Russian Young Researchers in Electrical and Electronic Engineering, ElConRus 2021*, 1032–1036. https://doi.org/10.1109/ElConRus51938.2021.9396535

Popkova, E. G., & Giyazov, A. (2021). Industrial and Manufacturing Engineering in Fight Against the Virus Threat: Perspectives of Increasing Quality Based on Digitalization and Industry 4.0. *International Journal for Quality Research*, *15*(1), 291–308. https://doi.org/10.24874/IJQR15.01-17

Rácz-Szabó, A., Ruppert, T., Bántay, L., Löcklin, A., Jakab, L., & Abonyi, J. (2020). Real-time locating system in production management. *Sensors (Switzerland)*, *20*(23), 1–22. https://doi.org/10.3390/s20236766

Riaño, C., Rodriguez, E., & Alvares, A. J. (2019). ScienceDirect Closed-Loop Inspection Architecture for Closed-Loop Inspection Architecture for Closed-Loop Inspection Architecture for Additive Manufacturing Based on Closed-Loop Inspection Based Architecture for Additive Manufacturing on Additive Manufact. *IFAC PapersOnLine*, *52*(13), 2782–2787. https://doi.org/10.1016/j.ifacol.2019.11.629

Sader, S., Husti, I., & Daróczi, M. (2019). Industry 4.0 as a key enabler toward successful implementation of total quality management practices. *Periodica Polytechnica Social and*

Management Sciences, *27*(2), 131–140. https://doi.org/10.3311/PPso.12675

Santos, G., Sá, J. C., Félix, M. J., Barreto, L., Carvalho, F., Doiro, M., Zgodavová, K., & Stefanović, M. (2021). New needed quality management skills for quality managers 4.0. *Sustainability (Switzerland)*, *13*(11), 1–22. https://doi.org/10.3390/su13116149

Savelyeva, M., & Shumakova, N. (2020). Innovative approach to training industry 4.0 experts. *Journal of Physics: Conference Series*, *1515*(3), 0–5. https://doi.org/10.1088/1742-6596/1515/3/032065

Saxby, R., Cano-kourouklis, M., & Viza, E. (2020). *An initial assessment of Lean Management methods for*. *32*(4), 587–601. https://doi.org/10.1108/TQM-12-2019-0298

Silva, B., & Campos, F. (2019). Indústria 4 . 0 e Sistemas ERP : revisão sistemática da literatura 2009-2019, achados, tendências e aplicações [Industry 4 . 0 and ERP Systems : systematic review of the literature 2009-2019 , findings , trends and applications]. *X Congresso Brasileiro de Enegnharia da Produção*, 1–13.

Siphoro, K. T., Bakama, E. M., Mukwakungu, C. M., & Sukdeo, N. (2020). Transition to Quality 4.0 and lean4.0 from traditional lean and quality systems: The case of a packaging company in South Africa. *2020 IEEE International Conference on Technology Management, Operations and Decisions, ICTMOD 2020*. https://doi.org/10.1109/ICTMOD49425.2020.9380619

Solod, A. R., Popova, A. V., Kalinina, Y. A., & Sinitsyna, A. M. (2020). Creation of integrated quality systems for standard solutions of it infrastructure organization, information security of the construction complex at the stage of the real estate object life cycle (construction stage). *Proceedings of the 2020 IEEE International Conference "Quality Management, Transport and Information Security, Information Technologies", IT and QM and IS 2020*, 148–152. https://doi.org/10.1109/ITQMIS51053.2020.9322854

Sony, M., Antony, J., & Douglas, J. A. (2021). Motivations, barriers and readiness factors for Quality 4.0 implementation: an exploratory study. *TQM Journal*. https://doi.org/10.1108/TQM-11-2020-0272

Subramanian, G., Patil, B. T., & Kokate, M. (2019). Review of Modern Technologies in Manufacturing Sector. *2019 6th IEEE International Conference on Advances in Computing, Communication and Control, ICAC3 2019*, 1–6. https://doi.org/10.1109/ICAC347590.2019.9036835

Tasmin, R., Nurul, S. R., Jaafar, I., Hamid, N. A. A., & Ngadiman, Y. (2020). The Readiness of Automotive Manufacturing Company on Industrial 4.0 Towards Quality Performance. *International Journal of Integrated Engineering*, *12*(7), 160–172. https://doi.org/10.30880/ijie.2020.12.07.018

Tissir, S., Fezazi, S. El, & Cherrafi, A. (2020). Industry 4.0 impact on Lean Manufacturing: Literature Review. *2020 13th International Colloquium of Logistics and Supply Chain Management, LOGISTIQUA 2020*, 2–4. https://doi.org/10.1109/LOGISTIQUA49782.2020.9353889

Tortorella, G. L., Giglio, R., & Dun, D. H. Van. (2019). *Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement*. 860–886. https://doi.org/10.1108/IJOPM-01-2019-0005

Trinks, S., & Felden, C. (2019). Image mining for real time fault detection within the smart factory. *Proceedings - 21st IEEE Conference on Business Informatics, CBI 2019*, *1*, 584–593. https://doi.org/10.1109/CBI.2019.00074

Turisová, R., Pačaiová, H., Kotianová, Z., Nagyová, A., Hovanec, M., & Korba, P. (2021). Evaluation of emaintenance application based on the new version of the EFQM model. *Sustainability (Switzerland)*, *13*(7). https://doi.org/10.3390/su13073682

Vasiliev, V. A., Aleksandrova, S. V., Aleksandrov, M. N., & Velmakina, Y. V. (2020). Possibilities for the Integration of Quality Management Tools and Methods with Digital Technologies. *Russian Metallurgy (Metally)*, *2020*(13), 1649–1652. https://doi.org/10.1134/S003602952013039X

Vo, B., Kongar, E., & Suarez-Barraza, M. F. (2020). Root-Cause Problem Solving in an Industry 4.0 Con. *IEEE Engineering Management Review*, *48*(1), 48–56. https://doi.org/10.1109/EMR.2020.2966980

Weckenmann, A., Bodi, Ş., Popescu, S., Dragomir, M., Hurgoiu, D., & Comes, R. (2019). Hit or miss? Evaluating the potential of a research niche: A case study in the field of virtual quality management. *Sustainability (Switzerland)*, *11*(5), 1–26. https://doi.org/10.3390/su11051450

Wszołek, G., Czop, P., Słoniewski, J., & Dogrusoz, H. (2020). Vibration monitoring of CNC machinery using mems sensors. *Journal of Vibroengineering*, *22*(3), 735–750. https://doi.org/10.21595/jve.2019.20788

Yadav, N., Shankar, R., & Singh, S. P. (2020). Impact of Industry 4.0/ICTs, Lean Six Sigma and quality management systems on organisational performance, *The TQM Journal*, *32*(4), 815–835. https://doi.org/10.1108/TQM-10-2019-0251

Yadav, N., Shankar, R., & Singh, S. P. (2021). Critical success factors for lean six sigma in quality 4.0. *International Journal of Quality and Service Sciences*, *13*(1), 123–156. https://doi.org/10.1108/IJQSS-06-2020-0099

Zonnenshain, A., & Kenett, R. S. (2020). Quality 4.0—the challenging future of quality engineering. *Quality Engineering*, *32*(4), 614–626. https://doi.org/10.1080/08982112.2019.1706744

Good practices and hindrances to integrate Lean Six Sigma with Industry 4.0 in the chemical sector

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Purpose - This paper identifies and systematized the good practices and hindrances for integrating Lean Six Sigma (LSS) and Industry 4.0 (I4) in a large and important Brazilian chemical company.

Design/methodology/approach - The research method used was a single case study in one of the biggest companies of the world chemical sector, recognized for innovating and constantly investing in its processes.

Findings – This paper identifies good practices and difficulties for integrating LSS and I4, considering the synergistic and dissonant aspects between the themes.

Practical implications - In an applied way this work allows managers to have access to knowledge capable of helping their companies to become leaner, agile, flexible, and digital, generating an important advantage over the competition.

Originality/value - In general terms, the systematization carried out in this work adds to the state of the art, important and unprecedented knowledge about good practices and difficulties between LSS and I4 in the chemical sector.

Keywords: Lean Six Sigma, Industry 4.0, Integration, Good Practices.

Paper type: Case Study

INTRODUCTION

The constant changes in the global economic scenario require companies to develop new strategies to overcome the challenges and ensure their survival in the market. Improving the quality of their products and services, reducing waste, shortening manufacturing and delivery times, and reducing costs are some of these challenges (Dombrowski, Richter and Krenkel, 2017a). Lean Six Sigma (LSS) and Industry 4.0 (I4) can help managers in overcoming these challenges. The first is a methodology for waste elimination and variability reduction (Laureani and Antony, 2012; Jayaram, 2016) and the second is a combination of digital technologies that assist companies in increasing productivity and improving competitiveness (Buscher and Borger, 2017; Dombrowski, Richter and Krenkel, 2017a; Tortorella and Fetterman, 2017).

LSS and I4 can be considered as complementary improvement strategies, which facilitates their integration and favors companies. As a result of this integration, companies can enjoy a powerful improvement strategy that eliminates waste while automating processes. Among the benefits generated by this integration, it stands out the use of LSS to eliminate waste and create leaner productive environments before the implementation of digital technologies, which can contribute to the maximization of the return on investments (Sanders, Elangeswaran, and Wulfsberg, 2016), and the use of I4 to collect, store and share data in real-time, with implementation of automated controls, and creation of simulation and prediction systems, to accelerate improvement projects (Buscher and Borger, 2017; Tortorella and Fetterman, 2017).

Studies relating LSS to I4 have been identified in the scientific literature and help to understand the relevance of the topic. Arcidiacono and Perroni (2018) and Chiarini and Kumar (2020) studied the benefits arising from this integration. Sony (2018) researched how LSS principles can contribute to the creation of cyber-physical systems and proposed a model for the development of these systems. Ganjavi and Fazlollahtabar (2021) developed a model to measure production sustainability from the use of LSS in the context of I4, and Yadav, Shankar and Singh (2021) and Bhat, Bhat and Gijo (2021) researched the critical success factors for LSS deployment in the context of I4.

Based on these works, this article expands the knowledge generated by identifying the difficulties of the integration process and a set of good practices aimed at maximizing the potential of its integration and the generation of results. Its realization enabled the filling of the research gap identified by Salvadorinho and Teixeira (2021), who observed the need for research that goes beyond an optimistic view on the relationship of these themes and also considers the contradictions and weaknesses of this relationship, presenting, in addition to guidelines to enhance their synergy, recommendations for countermeasures to possible conflicts.

Based on the above, the research question that guided the development of this work was: how is it possible to enhance the integration of LSS to I4 in an industry of the chemical sector, to generate a competitive advantage for this sector? To answer this question, its objective is to identify good practices that help companies to enhance the synergies and mitigate the dissonances between LSS and I4 aiming to generate a competitive advantage for companies in the sector. This objective was achieved using a case study conducted at a company in the chemical sector.

RESEARCH METHODOLOGY

This work is a case study conducted in a company in the chemical sector, from a set of procedures used to identify, analyze, and interpret the available evidence about a research question, in an impartial and repeatable way (Kitchenham and Charters, 2007). The single case study gets this classification when the researcher sticks to a single unit of analysis. The single case study has relevance when the analyzed object is representative, which meets this research, by analyzing one of the largest chemical companies in the world (Yin, 2017).

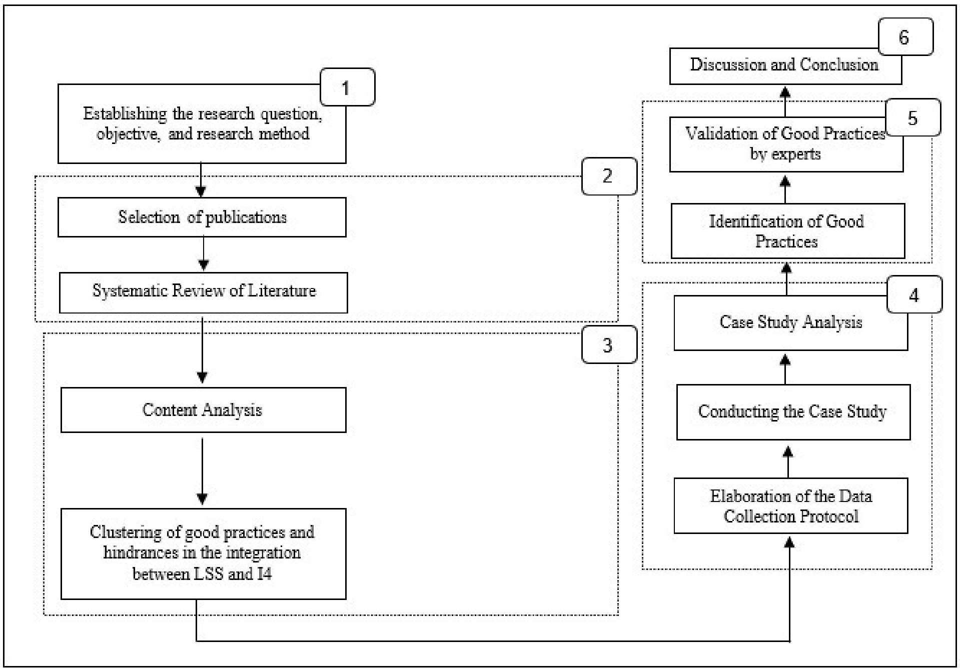

Figure 1 - Research Method Flow

In the first stage, the research question, objective, and method were established. In the second stage, a set of relevant articles on the subject studied were selected from the scientific base Scopus. The selection of articles was performed searches using the search strings "Lean Six Sigma and Industry 4.0 or Smart Manufacturing", "Lean and Industry 4.0 or Smart Manufacturing", and "Six Sigma and Industry 4.0 or Smart Manufacturing". The searches were considered articles and reviews published in the period from 2011 to 2021 in the English language. From the selected articles, a systematic literature review was conducted, considering the relevant contents of LSS and I4 individually and then of both associated themes.

In the third stage it was performed the content analysis, considering the eighty-nine papers addressing LSS and I4. From the content analysis, the difficulties in the integration of LSS to I4 were identified. In step four the data collection protocol was elaborated, and the case study was carried out, with data collection and analysis. In step five the good practices for integration of the LSS to the I4 were identified, being validated by experts in the theme. Finally, in step six the discussion and conclusion of the work were carried out respectively.

RESULTS

The results are presented in two sections: (1) content analysis, clustering of good practices and obstacles to integrate LSS and I4; and (2) case study development.

Content analysis and clustering

The LSS and I4 have complementary purposes, which allows their joint and integrated use in companies. Among the benefits provided by this integration are the rationalization and optimization of the deployment of technologies used in I4, allowing the maximization of the return on investments (Buscher and Borger, 2017, 2017; Dombrowski, Richter and Krenkel, 2017a; Tortorella and Fetterman, 2017). Thus, this combination does not only benefit the industry and can also help the service sector and public administration (Arcidiacono and Pierroni, 2018; Chiarini and Kumar, 2020).

Moreover, industrial revolutions, including I4 (4th revolution), have influenced society in three categories: people, processes, and technologies. It is observed that these categories are also influenced by LSS, which brings these two approaches even closer together. When worked in an integrated way, LSS and I4 themes can positively increase the influence on these three categories, boosting organizations' results (Arcidiacono and Pierroni, 2018). The integration of LSS and I4 has seven defined groups, from the literature analysis, being them: barriers, effects, benefits, similarities, models, management, research mapping, and advantages (Table 1).

Table 1 - Clustering of the contributions of papers on Lean and I4

Groups	Contributions	Author / Year
Barriers	Barriers to the integration of Lean and I4	Sanders et al. (2016)
Effects	Effects of Digitization on Lean	Roy, Mittag and Baumeister (2015); Rossini *et al.,* (2019); Ghobakhloo and Fathi (2020); Rosin et al. (2020)
Benefits	Benefits of Lean to I4	Dombrowski, Richter and Krenkel (2017a); Metternich *et al.,* (2017)
Similarities	Similarities in purpose	Kaspar and Schneider (2015); Dombrowski, Richter and Krenkel, (2017a); Dombrowski *et al.,* (2017b); Villalba-Diez *et al.,* (2019)
Models	Solutions for Lean and I4 integration	Pokorni *et al.,* (2017); Sony (2018)
Management	Impacts on organizational performance from the integration of Lean and I4	Tortorella and Fettermann (2017); Kamble, Gunasekaran, and Dhone (2020); Tortorella, Miorando and Cawley (2019a); Tortorella, Giglio and Van Dun (2019b)
Research Mapping	Characterization of research on Lean and I4	Buer, Strandhagen and Chan (2018)
Advantages	Advantages of LSS and I4 integration	Arcidiacono and Pieroni (2018); Chiarini and Kumar (2020)

In the first group (barriers), Sanders (2016) has the only article in this group, also addressing about the challenges of integration between LSS and I4. The second group, defined as Effects, addresses the impacts of I4 technologies on Lean principles. Roy, Mittag and Baumeister (2015) discuss the impacts of Lean integrated with I4 technologies, Rossini et al. (2019) the effects on European manufacturers, Ghobakhloo and Fathi (2020) the effects of digitization on small manufacturing companies and Rosin et al. (2020) the effects on waste reduction. The third group is called Benefits and contains the articles by Dombrowski, Richter and Krenkel (2017a) and Metternich et al. (2017), mentioning that success, in using I4 technologies, will depend on the implementation of Lean and this should precede initiatives to use the technologies. In the fourth group, Similarities, Kaspar and Schneider (2015) present a case study in the Logistics area and address the convergence between these themes; Dombrowski, Richter and Krenkel (2017a) discuss the relationship between Lean and I4 through a survey of two hundred and sixty companies in Germany; Enke et al. (2017) address the potential integration of Lean and I4 from the application of quality tools and Lean methods; and Villalba-Diez et al. (2019), how Lean management problem-solving behavior, can help Industry 4.0 leaders to choose suitable manufacturing systems.

The Models group, fifth group, Pokorni et al. (2017) discusses a solution for assessing the maturity of Lean integration with I4, focusing on companies in the manufacturing sector from existing models, and Sony (2018) presents a solution for using Lean combined with I4 in a healthcare environment. The sixth group, Management, represents the papers that address the impacts generated in the management of industrial organizations from the use of Lean with I4, as proposed by Tortorella and Fetterman (2017), Kamble, Gunasekaran, and Dhone (2020), Tortorella, Giglio and van Dun (2019b) and Tortorella, Miorando and Cawley (2019a). Only the paper by Buer, Strandhagen and

Chan (2018) is making up the 'Mapping Research' group, which is part of group seven. In this paper, the authors developed a mapping of Lean and I4 research. In the last group, named 'LSS and I4', the papers by Arcidiacono and Pieroni (2018), and Chiarini and Kumar (2020) are presented, which address respectively the application of LSS in I4 in a laboratory environment, and the benefits of integrating LSS and I4 in the industrial environment of Italian factories. Based on the results of the best practices and the obstacles to integration between LSS and I4, it was possible to structure the principles and elements that served as a guide for the single case study (Table 2).

Table 2 - Principles and Elements of LSS and I4

LSS Principle	LSS Elements	I4 Principle	I4 Elements
Customer Focus	Meeting Customer Needs; Long-term relationships	Scanning	Standardization; Virtualization; Decentralization; Flexibility; Control; Optimization
Develop leadership	Leadership Awareness; Definition of competencies; Leadership performance assessment; Definition of performance goals; Implementing communication processes; Resistance elimination	Connectivity	Integration; Secure Communication; Mobility; Collaboration; Complex systems management
Develop the workforce	Involvement and engagement; Forming multidisciplinary teams; Adequate selection; LSS training	Shared Data	Real time capability; Transparency
Manage projects	Project selection and prioritization; Focus on results; Creation of an improvement culture	Learning	Cognition; Improvement
Continuously improve the processes	Top management involvement; Empowering and mobilizing the workforce; Brainstorming and communication; Use of the appropriate tools	Predictive Power	Data and Scenario Analysis; Simulation
Use improvement tools	Workforce empowerment; Combination with management techniques	Self-Adjustment Capability	Self-configuration; Self organization; Self-optimization; Self prediction
Implement controls	Standardize processes; Identifying and controlling critical variables	-	-

Case Study

The company studied operates in the chemical segment, was founded in Germany, is one of the global leaders in its segment, and has been operating in the world market for over 150 years. The organization has its global headquarter based in Ludwigshafen, Germany, and is installed in over 80 countries. With a global sales volume of 59 billion euros, in 2020, the company has approximately 4200 employees working in Brazil. Founded in 1865, the company started its activities with the production of dyes. Currently, its portfolio is organized into six segments: Chemicals, Materials, Industrial Solutions, Surface Technologies, Nutrition, and Care and Agricultural Solutions.

In the company, the I4 theme is coordinated by an area called Digitalization of Operations and Technology. This area is also known in the company as the Smart Manufacturing Team (SM). It has management status, is formed by a team of 20 professionals, and is responsible for all initiatives related to I4 in South America. The Lean Six Sigma theme is coordinated by a management named

Operational Excellence (OE). As it happens in the SM management, OE is also structured by regions, and there is a manager responsible for South America. Both in the case of SM and OE, the managers and their teams are based in the state of São Paulo, Brazil.

On one of the pages of its website, the company cites that the use of digital services can provide real-time access to important information, and the use of integrated internal and external data can strengthen innovation and help the company to better predict the maintenance demands of its factories, reducing unexpected downtime.

As for the application of I4 technologies, SM management has been researching and developing solutions using Big Data, Synthetic Biology, Cyber Security, Cloud Computing, Analytics, Exoskeleton, Digital Twins, Additive Manufacturing, Internet of Things, Artificial Intelligence, Augmented Reality, Virtual Reality, Radiofrequency, Robots, Intelligent Sensors, Cyber-Physical Systems, Simulation, Wireless Networking, and 5G. Some of these technologies are being tested and integrated directly in Matrix South America lab. Some examples are solutions using Big Data, Cyber Security, Cloud Computing, Analytics, Digital Twins, the Internet of Things, Artificial Intelligence, Augmented Reality, Virtual Reality, and 5G, among others.

Regarding I4 Integration with Lean Six Sigma, the SM team highlights that I4 has contributed with:

- Identification of improvement opportunities from online mapping of process status;
- Online data collection to support improvement projects and analysis through statistical tools;
- Proof of the improvements, providing in a fast and online way the data that allows to prove the results obtained from the actions proposed in the Lean Six Sigma projects.

The areas of SM and OE are unanimous in recognizing that the LSS projects have contributed to the implementation of I4 from the identification and statistical proof of waste, bottlenecks, and inefficiencies of processes, signaling objectively in which should be prioritized the implementation of technological solutions. It is noteworthy that the OE area encourages the digitalization only of the so-called "healthy" processes. This way, the OE recommends that LSS improvement projects are executed before the processes are digitalized. A manager of the area mentions that teams are encouraged to adjust processes before taking them to the digital environment.

The SM and OE areas also recognize that the solutions linked to I4 have contributed to the company's improvement initiatives and projects. These solutions digitalize processes and provide reliable real-time data for LSS projects, reducing project execution time in the data collection phase and the verification of results in the control phase.

The OE area also highlights that I4 has assisted improvement initiatives in standardizing processes, collecting and sharing data, improving data reliability and reducing variability. On a scale from 1 to 5, the area points as 4 the I4 contribution for the LSS improvement projects.

In the company, there is evidence that the digitalization generated quality improvements, bringing positive impacts to the clients. Through the digitalization of its processes, the company has reduced the quality problems and the variations in the properties and characteristics of its products, increasing the satisfaction of its clients. Applications, in this sense, are not yet numerous, and according to the area manager, there is still plenty of room for new applications.

In this case, the connectivity of the systems and processes has improved the traceability of products and services. Through digitalization, the company has integrated the systems used in the various processes, enabling the exchange of data between them and traceability from systems, mobile devices, and Web platforms. This integration process is called verticalization in the company and, among the examples observed, the reverse logistics process that takes place for some of its products stands out. We also highlight the possibility of customers of some specific products to follow the progress of their orders through the Internet.

The connectivity of systems and/or equipment has also improved the traceability of manufacturing processes. Information generated by the various processes is transmitted in milliseconds and stored in large databases, allowing any events to be investigated accurately and quickly to identify equipment and/or operation faults.

For OE, digitalization has provided the necessary tools for leadership to be empowered through accurate information, better controls, and support in the decision-making process within improvement projects. The OE mentions that digitalization allows that the results generated from the improvement actions are instantly monitored and measured, speeding up the decision-making process, improving the assertiveness of the managers and the response time to correct deviations.

Regarding the connectivity of systems and equipment, the OE highlights that it increased the autonomy level of the leadership in its activities. The connectivity and the verticalization obtained from the digitalization contributed to the reduction of rework, increased data reliability, and increased the independence of the areas. With connectivity, information is made available between processes in a more agile and reliable way, allowing the leadership to act and decide without depending on the action of other areas, employees, or managers.

In addition, connectivity has increased the workforce's mobility, contributing to its development and with the results of the improvement projects. From mobile phones and tablets, employees can access their processes from any location, at any time, allowing them to monitor, evaluate and make decisions without being physically in the location where these processes occur, and thus have time and conditions to participate in improvement actions, training, and other activities.

The connectivity also favors the integration of multidisciplinary teams, during the execution of improvement projects. Independently of their geographical location, employees from different regions, areas and expertise, can be involved in improvement projects, visualizing processes in real-time and consulting historical bases, favoring the integration, the exchange of experiences, the engagement and consequently the results obtained in the projects. One example is the use of augmented reality glasses that offer maintenance teams the possibility of carrying out interventions in the field, and in real-time transmitting images of the activities being carried out to teams of engineers located hundreds of kilometers away.

For OE, digitalization provides the necessary tools to empower the workforce through the provision of reliable information, better controls, and automation of part of their activities in the scope of improvement projects. According to OE, digitalization speeds up the data collection in the projects, improves the reliability of the information obtained, helps the workers to evaluate the results of the improvement projects, and makes possible the implementation of fail-proof controls and systems that help to maintain the gains of the improvement actions.

These controls are made possible through solutions that monitor the main variables of the processes, indicate trends, issue alerts, and promote, in some cases, the self-adjustment of processes and equipment. In addition, these controls are based on data from a complex digital sensing system that increases the reliability of these controls. With the aid of connectivity, these controls are mostly decentralized, being accessed from any location through mobile devices.

In this case, it was observed that the sharing of data, in the I4 environment, has contributed with a greater engagement of the workforce in the improvement projects. During the meetings for the conduction of improvement projects, the employees can visualize in real-time what happens with the processes, with their activities and with the equipment.

This sharing also favors the monitoring of the processes and the precise intervention by the employees when deviations occur. The OE states that by sharing data in real-time, operators evaluate the performance of processes and equipment, reacting quickly and proactively to adjust them. The OE also mentions that, in some cases, data sharing feeds automatic systems that promote the self-adjustment of equipment and processes.

In addition, digitization allows historical data to be accessed and hundreds of process variables to be cross-referenced and analyzed, enabling employees to have enriching discussions about possibilities for improvement in LSS projects.

For OE, digitalization generates solutions that optimize the use of resources and favor management within LSS improvement projects. With the automation of the data collection, the crossing of variables and the availability of information in real-time, the managers of the improvement projects can use the human resources better, directing them to more noble activities that involve analysis and decision making. The automatic data collection also contributes with the use of the LSS improvement tools. Linear and multiple regressions between variables are accomplished in real-time, allowing the improvement teams to know better the behavior of the processes and the impacts of a determined variable in the result of a process.

There is evidence, in the company, that the digitalization helped in the processes of standardization. The OE cites that digitalization improved the reliability and the speed of data collection, allowing the improvement teams to correct eventual deviations during and after the execution of the LSS projects. In addition, the automatic collection of KPI's (Key Process Indicators) has taken the company to a new management level. The OE mentions that digitalization has enabled the creation of alerts and, in some cases, failsafe systems, which help employees in performing their activities and reduce the possibility of deviations.

It was observed in the case study that digitization helped to reduce human interference in processes. Examples, in this sense, are the mixing of chemicals in the manufacture of fertilizers and paints. Less interference helped standardize processes, eliminated quality problems and reduced variability in the chemical composition of products. In addition, greater speed and accuracy in process setup were observed, increasing the productivity of the manufacturing lines.

Studies have been promoted by the company for the implementation of solutions aimed at problem prediction and implementation of solutions that promote self-adjustment of systems and/or equipment, helping to avoid quality deviations. The company also developed, based on a series of algorithms, a digital platform called "Lab Assistant" that helps customers identify the raw materials needed and appropriate formulations for the creation of decorative paints. With this platform, customers quickly identify the best formulation recommendations for creating their products. In the future, this type of solution may use machine learning to improve formulations and enhance customer satisfaction.

On the other hand, no evidence was found from the case study that machine learning is contributing to leadership and workforce development. Nor was any evidence found that it has:

- Streamlined improvement projects;
- Improved quality and manufacturing processes;
- Helped predict problems in processes/equipment;
- Favored the optimization of processes;
- Contributed to the implementation of fail-safe systems.

Regarding the dissonances identified in the scientific literature, the OE and SM areas believe that digitalization brought greater complexity to the management process due to the diversity of technologies and equipment. According to these areas, this dissonance is a great challenge and could indeed generate difficulties in the management process. However, with planning and adequate staff training, this challenge has been overcome naturally.

The technical training of the staff is another major challenge for the company. During LSS projects which involve the use and application of technologies, it is common that the company needs to invest time and financial resources to prepare the teams, going against the proposal of simplicity, agility and zero investment proposed by LSS projects. In this sense, the OE area has reinforced the importance of digitalization of the processes considered "healthy" so that the digitalization is effective, and the company can recover the return on investments.

During LSS projects, it is also common that the teams to look for technological solutions that help reduce waste, generating the need for investments in technology, going in the opposite direction of the LSS essence of implementing improvement projects with zero cost.

This dissonance is a concern of the OE area and has demanded greater rigor in the definition of projects and in the calculations that indicate the return on investments. According to OE, the improvement projects must indicate which will be the impact of the investment and if it will bring the expected return to the company. This way, the decision about the investment is based on the evidence of the financial return.

In the implementation of some solutions used in I4, different equipment and communication protocols need to be installed and integrated, creating complex digital environments with high maintenance costs, which confronts the proposal of simplicity and lean solutions proposed by the LSS.

This scenario has required the company to also be very strict in planning and managing maintenance costs. Another important action identified, in the company, is the research and development of technology suppliers that are willing to work collaboratively to create solutions that reduce the need for interfaces and different communication protocols. Based on the description of the single case study, there follows a systematization of the good practices and constraints that can be highlighted according to Table 3.

Table 3 - Good practices and Hindrances in integrating LSS and I4

Good Practices	**Hindrances**
Consider continuous improvement as a value; Have a clear strategy geared towards innovation and digitization; Recognize I4 as an enabler of opportunities; Establish partnerships with startups and teaching and research institutions; Create a 4.0 laboratory for research, development, and technology integration; Have specific teams for improvement and digitization; Investiment in digital technologies; Investiment in staff training; Focus on cyber security; Approve equipment, systems and communication protocols; Standardize the technologies and communication protocols used.	Management of complex environments with different technologies and communication protocols; Lack of skilled labor to implement and support the various technologies used in Industry 4.0; High implementation and maintenance costs of different technologies.

DISCUSSIONS AND CONCLUSION

The company studied has a strong potential to enhance the integration of LSS with I4. It has an employee structure for both I4 and LSS. The perception of its employees is that there is an 80% integration between both, with room to further increase synergy between both. About to the benefits mentioned by the company, one can highlight the inhibition of sudden stoppages in the production line, the adjustments of processes before digitizing them and quality improvement, and the decrease in process variation due to digitization (Rosin et al. 2020; Chiarini and Kumar 2020).

Concerning to the main dissonances presented by the company, it stands out the greater complexity of management and the difficulties to carry out training and capacity building for its employees. The integration between the I4 and the LSS may generate conflicts since the interests of the technology sectors are not always the same as the improvement propositions. In the case of I4, there is the need for large investments for the implementation of technologies and staff training, and in the case of the LSS, a huge complexity in managing the integrations of the technologies used (Sanders et al. 2016).

These adaptations are important because the globalized world economic scenario requires managers of industrial companies to define strategies that help keep their organizations competitive in the face of competition. These strategies need to contribute to the reduction of waste and process variability and make operations agile and flexible to meet increasingly demanding and selective consumers.

Globalization, competition, and the access of customers to a higher level of information about products and services are factors contributing to the constant change in the consumer market's behavior. This market expects companies to have more and more quality, fair price, ethical behavior, and social and environmental responsibility.

Understanding this scenario and defining strategies to improve the competitiveness of industrial companies are some of the issues that must be present on the agenda of managers. Strategies to make organizations more competitive are available in the scientific literature and in the business world. However, new strategies are necessary to face the technological evolution and the constant change in consumer behavior.

The LSS integrated to I4 is a recent theme and can be one of these strategies. In this context, this work aims to propose guidelines for the implementation and management of LSS integrated to I4 so that industrial companies can be more competitive. In the scientific literature, it is identified other works that address this integration, however, in a more generalist way and without a deeper and broader discussion about the synergies, dissonances and guidelines for integration of the themes.

Walking towards the achievement of the objective proposed in this article, a review of scientific literature was conducted, followed by a content analysis for the systematization of the LSS and I4 principles. As a result of these phases, eight groups of the integration between LSS and I4 were systematized. These principles helped to better understand the dynamics of the themes and will be fundamental for the proposition of the guidelines. After this construction, the development of the case study was possible.

In an applied way, this work allows managers to have access to knowledge capable of helping their companies to become leaner, more agile, flexible, and digital, generating an important advantage over to the competition. In general terms, the systematization performed in this work adds to the state of the art, important and unprecedented knowledge about good practices and difficulties between LSS and I4 in the chemical sector.

The main limitation of this work was the lack of comparisons with other analysis units, either from the chemical sector itself or from other economic sectors. Given this, it is recommended future studies that consider multiple case studies and maturity matrix analysis to verify the level of integration between LSS and I4 in other organizations.

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REFERENCES

Arcidiacono, G. and Pieroni, A. (2018). “The Revolution *Lean Six Sigma* 4.0”, *International Journal on Advanced Science, Engineering and Information Technology*, Vol. 8, No.1, pp. 141.

Bhat, V.S., Bhat, S. and Gijo, E.V. (2021), "Simulation-based lean six sigma for Industry 4.0: an action research in the process industry*", International Journal of Quality & Reliability Management*, Vol. 38 No. 5, pp. 1215-1245.

Buer, S.V.; Strandhagen, J. O. and Chan, F. T. S. (2018). “The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda”, *International Journal of Production Research,* Vol. 1, No.1.

Buscher, U.and Böger, F. (2017). “Wie sich Industrie 4.0 und *Lean* gegenseitig befruchten”, *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb*, Vol. 112, No.7–8, pp. 518–521.

Chiarini, A. and Kumar, M. (2020). “Lean six sigma and industry 4.0 integration for operational Excellence: Evidence from italian manufacturing companies”, *Production Planning and Control*, , Vol. 2020, No.1.

Dombrowski, U.; Richter, T. and Krenkel, P. (2017a). “Wechselwirkungen von ganzheitlichen produktionssystemen und industrie 4.0: Eine use-case-analyse”, ZWF *Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb*, Vol. 112, No.6, pp. 430–433.

Dombrowski, U.; Richter, T. and Krenkel, P. (2017b). “Interdependencies of Industrie 4.0 & *Lean* Production Systems: A Use Cases Analysis”, *Procedia Manufacturing,* Vol. 11, No. June, pp. 1061–1068.

Enke, J.; Meister, M.; Metternich, J.; Genne, M. and Brosche, J. (2017). “Der Weg zur *Lean* Quality 4.0. ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb”, Vol. 112, No.9, pp. 612–615.

Ganjavi, N. and Fazlollahtabar, H. (2021) "Integrated Sustainable Production Value Measurement Model Based on Lean and Six Sigma in Industry 4.0 Context," in *IEEE Transactions on Engineering Management*.

Ghobakhloo, M. and Fathi, M. (2020). “Industry 4.0 and opportunities for energy sustainability”, *Journal of Cleaner Production*, Vol. 295, No. 1.

Jayaram, A. (2016).” Lean six sigma approach for global supply chain management using industry 4.0 and IIoT”, *Paper presented at the Proceedings of the 2016 2nd International Conference on Contemporary Computing and Informatics*, pp, 89-94.

Kamble, S., Gunasekaran, A. and Dhone, N. C. (2020). “Industry 4.0 and lean manufacturing practices for sustainable organisational performance in indian manufacturing companies”, *International Journal of Production Research*, Vol. 58, No. 5, pp. 1319-1337.

Kaspar S. and Schneider M. (2015). “Lean and industry 4.0 in the field of intra logistics: Efficiency improvement by combination of the two approaches”, *Productivity Management,* Vol .20, No. 5, pp. 17-20.

Kitchenham, B. and Charters, S. (2007) Guidelines for Performing Systematic Literature Reviews in Software Engineering. *Evidence Based Software Engineering Technical Report*.

Laureani, A., Antony, J. (2017). “Leadership characteristics for lean six sigma”, *Total Quality Management and Business Excellence*, Vol.28, No.3, pp. 405-426.

Metternich, J.; Müller, M.; Meudt, T. and Schaede, C. (2017). “Lean 4.0 - Zwischen widerspruch und vision”, *ZWF Zeitschrift fuer Wirtschaftlichen Fabrikbetrieb*, Vol. 112, No. 5, pp. 346–348.

Pokorni, B., Schlund, S. S., Tomm, A., Euper, D., Mehl, D. and Palm, D. (2017). “Production assessment 4.0 - development of a maturity model to assess the lean management and industrie 4.0 maturity of manufacturing companies”, *ZWF Zeitschrift Fuer Wirtschaftlichen Fabrikbetrieb*, Vol. 112, No. 1, pp. 20-24.

Rossini, M., Costa, F., Staudacher, A. P. and Tortorella, G. (2019). “Industry 4.0 and lean production: An empirical study”, *Paper presented at the IFAC-PapersOnLine*, Vol. 52, No. 13, pp. 42-47.

Rosin, F., Forget, P., Lamouri, S. and Pellerin, R. (2020). "Impacts of industry 4.0 technologies on lean principles", *International Journal of Production Research,* Vol. 58, No. 6, pp. 1644-1661.

Roy, D.; Mittag P.and Baumeister M. (2015). "Industrie 4.0 – impact of digitalization on the five lean principles", *Productivity Management*, Vol. 20, No. 2, pp. 27-30.

Salvadorinho, J; Teixeira, T. (2021). "Organizational knowledge in the I4.0 using BPMN: a case study", *Procedia Computer Science*, Volume 181, 2021, Pages 981-988.

Sanders, A.; Elangeswaran, C. and Wulfsberg, J. (2016). "Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing", *Journal of Industrial Engineering and Management*, Vol. 9, No. 3, pp. 811-833.

Sony, M. (2018). "Industry 4.0 *and Lean* management: a proposed integration model *and* research proposition", *Production and Manufacturing Research,* Vol. 6, No. 1, pp. 416–432.

Tortorella, G. L. and Fettermann, D. (2017). "Implementation of Industry 4.0 *and Lean* production in Brazilian manufacturing companies", *International Journal of Production Research*, Vol. 7543, No. 1, pp. 1–13.

Tortorella, G. L., Miorando, R., Mac Cawley, A. F. (2019a). "The moderating effect of Industry 4.0 on the relationship between *Lean* supply chain management *and* performance improvement", *Supply Chain Management*, Vol. 24, No. 2, pp. 301–314.

Tortorella, G. L., Giglio, R., & Van Dun, D. H. (2019b). "Industry 4.0 adoption as a moderator of the impact of lean production practices on operational performance improvement", *International Journal of Operations and Production Management,* Vol. 39, No. 1, pp. 860-886.

Villalba-diez, J., Zheng, X., Schmidt, D. and Molina, M. (2019). "Characterization of industry 4.0 *Lean* management problem-solving behavioral patterns using EEG sensors *and* deep learning. Sensors", *Switzerland*, Vol. 19, No. 13.

Yadav, N., Shankar, R., and Singh, S. P. (2021). "Hierarchy of critical success factors (CSF) for Lean Six Sigma (LSS) in quality 4.0", *International Journal of Global Business and Competitiveness,* Vol. 16, No.1, pp. 1-14.

Yin, R. K. (2017). "Case Study Research Design and Methods (6th Ed.)". *Thousand Oaks, CA: Sage Publishing*.

The Challenges of Remote Work to the development of a TQM Culture

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ABSTRACT

Purpose – The purpose of the current paper is to analyze the challenges raised by remote work to the development of a TQM culture. In addition, a framework to assess an organization's capacity to build a quality management culture within the context of remote (and hybrid) forms of work is proposed.

Design /approach – The paper is based on a critical analysis of relevant literature. From this literature review, and using the OCTAPACE model, the organizational values that facilitate the implementation of TQM are derived and the impacts of the new working scenario on the adoption and diffusion of such values are examined.

Findings – The impact of remote forms of work on the various OCTAPACE culture dimensions is not the same. While autonomy is expected to increase, collaboration and trust are particularly threatened. Additionally, to have a strong TQM culture, openness, collaboration, trust, and experimentation need to be fostered.

Research limitations/implications- The paper is mainly conceptual and the proposed framework needs to be empirically validated in future studies. However, it is possible to conclude that, in order to foster a TQM culture, occasional face-to-face meetings need to take place and changes in leadership styles need to occur.

Originality/value- Management literature has extensively discussed the advantages and shortcomings of remote work. Yet, its effects on quality management have received considerably less attention.

Keywords: TQM, organizational values, remote work, socialization

Paper type: Conceptual paper

INTRODUCTION

Total Quality Management (TQM) can be defined as a management philosophy that promotes customer focus, employee involvement, and (continuous) improvement, supported by an adequate organizational structure and a set of methodologies and tools (Sinclair and Collins, 1994), thus embracing both the so-called "soft" aspects (attitudinal and behavioral) and "hard" aspects (procedures and techniques) (Wu, Zhang and Schroeder, 2011; Ababneh, 2020).

Although there is no absolute consensus in the literature about the drivers of successful TQM implementation, the role of an organizational culture aligned with the quality management principles and practices has systematically been emphasized (Hildebrandt *et al.*, 1991; Kuo and Kuo, 2010; Gimenez-Espin, Jiménez-Jiménez and Martínez-Costa, 2013; Gambi *et al.*, 2015; Patyal and Koilakuntla, 2018; Akemu and Abdelnour, 2020; Hilman, Ali and Gorondutse, 2020). Therefore, managers should be able to create an environment that is supportive of the adoption of TQM principles and practices and build a strong culture that fosters them. However, as highlighted by Dimitrantzou *et al.* (2021), further research is needed to understand the cultural characteristics upon which companies should focus in order to improve TQM implementation.

Organizational culture is communicated and reinforced through different channels. Socialization, regarded as a way to teach new members cultural values and beliefs, plays an important role in this regard (Feldman, 1986). Yet, the effectiveness of these channels and strategies is threatened by changes linked to the emergence of new working forms, remote work in particular.

Although the adoption of remote work is not a novelty for modern organizations since it has been around since the 1970s and has been pointed out as one of the most prevalent bases of flexibility programs since the 1990s (de Vries, Tummers and Bekkers, 2019), the recent COVID 19 pandemic has accelerated the emergence of either remote or hybrid forms of work (Palumbo, 2020; Palumbo, Manna and Cavallone, 2020). Eurostat statistics reveal that, in 2016, at least 5% of the employees in Europe worked remotely on a regular basis, a number that is far from the United States reality (with 23% of the employees in the same situation). Even if there is a relative consensus that, as the pandemic situation eases, many workers will return to the 'offices', it is also widely accepted that some changes will remain and have definitely altered working models.

Management literature has extensively discussed the advantages and shortcomings of having employees working away from the organization's premises (de Vries, Tummers and Bekkers, 2019; Palumbo, 2020). Better work-life balance for employees, reduced costs for the firms, and environmental gains due to less commuting are frequently mentioned (de Vries, Tummers and Bekkers, 2019; Asatiani *et al.*, 2021). While conflicting evidence exists in what concerns the effects of remote work on employee satisfaction and efficiency, some drawbacks are widely emphasized.

Among such major problems, integration and socialization have been highly stressed (de Vries, Tummers and Bekkers, 2019). Yet, the effects of remote work on quality management have received considerably less attention. One of the few exceptions is the research conducted by Palumbo, Manna and Cavallone (2020), aimed at understanding the role of soft TQM in addressing the side effects of remote work, in particular in terms of low organizational commitment of employees. Thus, their work analyzes the specific role of soft TQM elements in mediating the relationship between home working and work-life balance and does not address the impact of remote work in TQM culture.

The purpose of the current research is to analyze the challenges raised by remote work to the development of a TQM culture, by identifying the organizational values that facilitate the adoption of TQM and evaluating how those are potentially affected by remote, and, to a smaller scale, hybrid forms of work. Following such discussion, a framework to assess an organization's capacity to build a quality management culture is proposed.

The remainder of the paper is structured as follows. In the next section, some relevant literature that discusses the ingredients of a TQM culture and the consequences of remote forms of work is reviewed. Then, the approach followed in this paper to derive the components of the proposed framework is described. The following section is dedicated to the presentation of the organizational values that need to be closely monitored if a TQM culture is to be fostered and to the analysis of their impact on key TQM elements. Considering the way remote work tends to affect the diffusion and assimilation of important organizational values, a grid to be potentially used when assessing the organization's efforts to enhance an appropriate TQM culture is presented. The paper concludes with some final remarks.

LITERATURE REVIEW

Organizational Culture and Quality Culture

Organizational culture guides people's decisions and behaviors (Wu, Zhang and Schroeder, 2011) and determines what actions are considered acceptable and unacceptable while being regarded as an important predictor of effectiveness and organizational performance and a significant source of competitive advantage (Powell, 1995; Dimitrantzou *et al.*, 2021).

One of the most well-known definitions of organizational culture is provided by Schein (2010), who argues that it corresponds to a pattern of shared values, assumptions, and beliefs that shape people's behaviors at work, as they learn how to adapt and integrate into an organization. Similarly, Robbin

(2004) defines organizational culture as a complex entity of values, beliefs, behavior norms, meanings, and practices shared by the personnel within an establishment.

Different frameworks have been proposed in the literature to describe organizational cultures. At a macro level, Hofstede (1980) identified five dimensions on which the culture of different countries differ. Looking at organizations, Schein (2010) suggests three levels: artifacts, exposed beliefs and values, and underlying assumptions. The most visible components of the organizational culture correspond to the artifacts, which include aspects such as structures, practices and processes, rituals, technology, manner of dress, and language. Behind observed artifacts are exposed beliefs and values, which are expected to favor creativity, problem-solving, and working with others. The deepest, and most difficult to change, level corresponds to underlying assumptions, which embody deep-rooted behaviors and comprise elements such as perceptions, thoughts, and feelings. Shared basic assumptions are perceived as self-evident and not questioned by members, thereby strongly influencing how organizational members act, think and feel in the organizational context.

Similarly, some literature (e.g. Giorgi, Lockwood and Glynn (2015)) identifies two components of organizational culture: symbolic and pragmatic. While the former corresponds to explicitly declared values and practices, the latter emerges from day-to-day work within organizations, when declared values are adapted and revealed in the patterns of behavior adopted by the individuals. These two types of components are not independent: as pointed out by Asatiani *et al.* (2021), symbolic values provide a framework for pragmatic actions, and pragmatic action, in turn, influences symbolic values.

A popular cultural model is Hofstede's (2011) framework of Power Distance, Uncertainty Avoidance, Individualism-Collectivism, Masculinity-Femininity, Long Term-Short Term Orientation, and Indulgence-Restraint. Likewise, Quinn and Rohrbaugh' (1981) competing values framework has been attracting considerable attention among researchers. Based on this framework, van Muijen and al. (1999) identified four major organizational culture orientations, namely support orientation (internally focused and emphasizing flexibility), innovation orientation (externally focused and emphasizing flexibility), rule orientation (internally focused and emphasizing control), and goal orientation (externally focused and emphasizing control).

Pareek (2003, *apud* Sinha and Dhall, 2020) has identified eight dimensions that might be used to describe an organizational culture, namely openness, confrontation, trust, authenticity, pro-action, autonomy, collaboration, and experimentation (OCTAPACE).

The so-called soft TQM elements are tightly related to people management practices and, as argued by Palumbo, Manna and Cavallone (2020), include mechanisms to increase work engagement, employees' empowerment and organizational trust.

According to Viljoen and Van Waveren (2008), quality culture refers to the specific part of the organizational culture that is more closely related to the organization's quality program. The authors thus suggest the following components of the quality culture value system: management involvement; supportive managerial action; continuous learning and training; rewards, recognition and celebration; constant on target communications; tracing of the right indicators; and utilization of quality improvement teams, quality planning and unit-level quality. In an attempt to develop a Total Quality Culture model, Kanji and Yui (1997) propose the following people elements: top management commitment, teamwork, internal customer-supplier relationships, human-oriented, ability to use quality control tools, everyone participation and motivation.

Regardless of the organization's cultural features, it is important to consider the various ways values and beliefs are created and disseminated. The organization's founders and leaders are important sources, but other mechanisms play also a relevant role, such as company artifacts, the physical layout of the space, dress codes, ceremonies, etc. Most of these mechanisms take place in traditional working environments, but, as organizations move to remote and hybrid models, new challenges arise.

Remote work, communication and socialization processes

Both the technology and recent extreme events, such as, in particular, the COVID 19 pandemic, have contributed to the emergence of virtual work environments and to the increasing use of remote (and hybrid) forms of work. Most organizations have become hybrid, combining face-to-face and remote work, with varying extents of each. Clearly, some occupations are more impacted by this trend than others, with knowledge-intensive jobs being propense to be performed in virtual work environments (Asatiani *et al.*, 2021).

Different forms of remote work have been acknowledged in the literature and the use of the associated terminology is often confusing. Teleworking is one of the most popular forms of remote work. It refers to a flexible work arrangement in which "employees perform all or a substantial part of their work physically separated from the location of their employer, using IT for operation and communication" (Baruch, 2001, p. 114). Work duties might be carried out at home (home-based telework), from an office that is remote from the main office (teleworking from remote offices), or from different places at different moments as it happens for people whose work involves travel and/or spend time on customers' premises (mobile telework).

In any case, the inability to rely on physical interactions between employees imposes specific challenges in highly virtual work environments. For the purposes of the current paper, our focus is on the way organizational culture is disseminated and we use as a reference remote work conducted from home, as this is the most common and frequently used form.

As stressed by Palumbo, Manna and Cavallone (2020), home working, by weakening communication and employees' ties with the organization, makes it more difficult for them to make sense of their job, tasks, and relationships at work.

Tacit knowledge is an important organizational asset and is typically shared when individuals get together in the work environment. Building such knowledge is particularly important to turn new employees into effective members. As Oshri, Kotlarsky and Willcocks (2007) emphasize, the socialization process involves interactions among the members of an organization whereby individuals exchange tacit knowledge, Mentorship and training are important for effective socialization, but day-to-day interaction with colleagues is irreplaceable.

In virtual organizations or when most work is done remotely, material cues of the organizational culture disappear and communication becomes harder. In this context, employees' identification with the organization is weakened.

It becomes evident in this regard that the pragmatic components of the culture (i.e., those, as described earlier, that emerge from the day-to-day work of individuals in an organization) are particularly affected. In the absence of frequent face-to-face interaction among employees, values and goals are likely to be interpreted in different ways leading to misalignment (Asatiani *et al.*, 2021). The problems of nurturing organizational culture are likely to be even greater in culturally diverse work environments (Asatiani *et al.*, 2021).

Moreover, previous research has shown that the negative consequences of remote work are amplified when home-based teleworking is adopted as an answer to unforeseen and contingent challenges (Palumbo, 2020), which calls managers' attention to the importance of planning and designing an appropriate setting for remote work.

RESEARCH METHODOLOGY

In the previous section, two different literature streams were reviewed: one that discusses the ingredients of a TQM culture and one that evaluates the organizational consequences of remote forms of work. From this literature review, the organizational values that facilitate the implementation of TQM are derived and the impacts of the new working scenario on the adoption and diffusion of such values are examined.

In the identification of the organizational values that support a quality culture and that might be particularly at stake when organizations adopt remote (and hybrid) forms of work, the OCTAPACE model, briefly presented in the literature review section, is used. The OCTAPACE model was selected because it is focused on the organizational level, it has been used in research studies in multiple contexts and it comprises operational scales to measure each of its dimensions making it easier to understand its content validity.

Next, the contribution of such values to the main quality culture components is examined. Finally, taking into account how these values are being threatened by remote work forms, a grid to assess the way organizations are addressing such challenges is proposed.

DEVELOPMENT OF THE PROPOSED FRAMEWORK: MAIN COMPONENTS

Organizational values to be closely monitored

In their study, Sinha and Dhall (2020) have proposed the items depicted in Table 1 to assess each of the OCTAPACE model constructs.

Table 1 – Components of the OCTAPACE model and expected impact of remote work forms

Organizational culture dimensions	Items	Expected Impact of Remote Work Forms
Openness	• Free interaction among employees • Genuine sharing of information and feelings in meetings. • Free communication between seniors and subordinates. • Effective managers cover their feelings. • Free communication across levels helps in problem solution	Moderately negative
Confrontation	• Surfacing problems is not sufficient; we should find the solution. • Facing challenges inherent in the work situation. • In-depth analysis of interpersonal problems. • Facing rather than escaping problems. • Evade responsibility by passing the problem on to someone else	Slightly positive
Trust	• Trust begets trust • Confiding in seniors without fear of distrust • Interpersonal contact and support among people • Offering help to employees and colleagues in a crisis • People cannot rely on others in times of crisis	Strongly negative
Authenticity	• People generally are what they appear to be • Owning up to mistakes • Congruity between feelings and expressed behavior • Tactfulness and even a little manipulation to get things done • Saying a polite lie is preferred to telling an unpleasant truth.	Slightly negative
Pro action	• A stitch in time saves nine • Prevention is better than cure • Considering both optimistic and pessimistic aspects before action • Seniors encourage subordinates to think and take action about their development • Preventive action on most matters	Slightly negative
Autonomy	• In order to motivate employees, they should be given autonomy to plan their work • Complying with seniors rather than acting on your own • Taking independent action related to jobs • Close supervision and direction of employees • Autonomy of employees results in indiscipline	Moderately positive
Collaboration	• Employees' participation in developing organizational goals contributes to productivity • Acknowledging and appreciating assistance offered by others • Teamwork and team spirit • Performing immediate tasks rather than being concerned with large organizational goals • Usually, teamwork reduces individual accountability	Strongly negative
Experimentation	• Thinking and doing novel things supports the organization's vitality • Making genuine attempts to transform behavior based on feedback • Encouraging employees to take a new look at how things are • Attempting novel ways of solving problems • In today's competitive situations, consolidation and stability are more important than experimentation	Slightly negative

Source: Adapted from Sinha and Dhall (2020)

The impact of the adoption of remote forms of work on the various organizational culture dimensions was estimated based on the judgmental analysis of the author, taking into account how the inexistence of face-to-face interaction and the absence of a traditional office, where routines and shared values are communicated through physical artifacts, might affect them. To simplify, those impacts were classified as positive or negative and only three levels of intensity have been considered (low, moderate, or high). Even if a certain degree of subjectivity must be assumed when making such an assessment, what matters is to identify which values are potentially affected the most.

In fact, as depicted in the last column, the impact of remote forms of work upon these dimensions is not the same. Autonomy, for instance, is expected to increase when employees work remotely since they experience greater freedom to plan and organize their work tasks. On the other hand, perceived (and real) professional isolation has a strong negative impact on collaboration and trust. As reported in previous studies (de Vries, Tummers and Bekkers, 2019), employees consider they lack interaction with colleagues when they work remotely.

It becomes also clear that the effects of remote work on organizational culture dimensions depend on the attitudes and behaviors of leaders. As suggested by de Vries, Tummers and Bekkers (2019. p. 578), in remote work environments, “direct coworker support and empathy may not be available, and subordinates may then have a greater need for considerate behavior from their leader”. Moreover, leaders may (or may not) use the possibilities given by technologies to increase the technocratic control over remote workers (Bathini and Kandathil, 2020).

Contribution of organizational values to TQM

Not all the dimensions proposed in the OCTOPACE model have the same importance to foster a TQM culture. As described earlier in the paper, a quality culture value system mainly includes the following elements:

- Management involvement and support;
- Everyone participation;
- Teamwork;
- Continuous learning and training;
- Open communication;
- Recognition of individual and team efforts and achievements

These elements correspond to the quality culture ingredients that were commonly identified in previous works, as described previously.

For each of these values, the various dimensions of the OCTAPACE model were ranked based on their expected importance to foster them. Thus, if a high correlation is expected to exist between a certain dimension of the OCTAPACE model and a particular TQM element, its importance was classified as high. If, on the contrary, looking at the items that are used to measure one specific OCTAPACE dimension there seems to be not much connection with the TQM element at stake, the importance is classified as low. The way each OCTAPACE dimension contributes to the development of a TQM culture is expected to be relatively universal, but the importance of each TQM value to a particular organization is context-specific. For instance, depending on the industry and type of products and services produced, teamwork might be more or less critical.

As shown in Figure 1, if these values are to be nurtured, particular attention needs to be given to the openness, collaboration, trust, and experimentation dimensions, given their close association with the people involvement and the (continuous) improvement pillars of TQM.

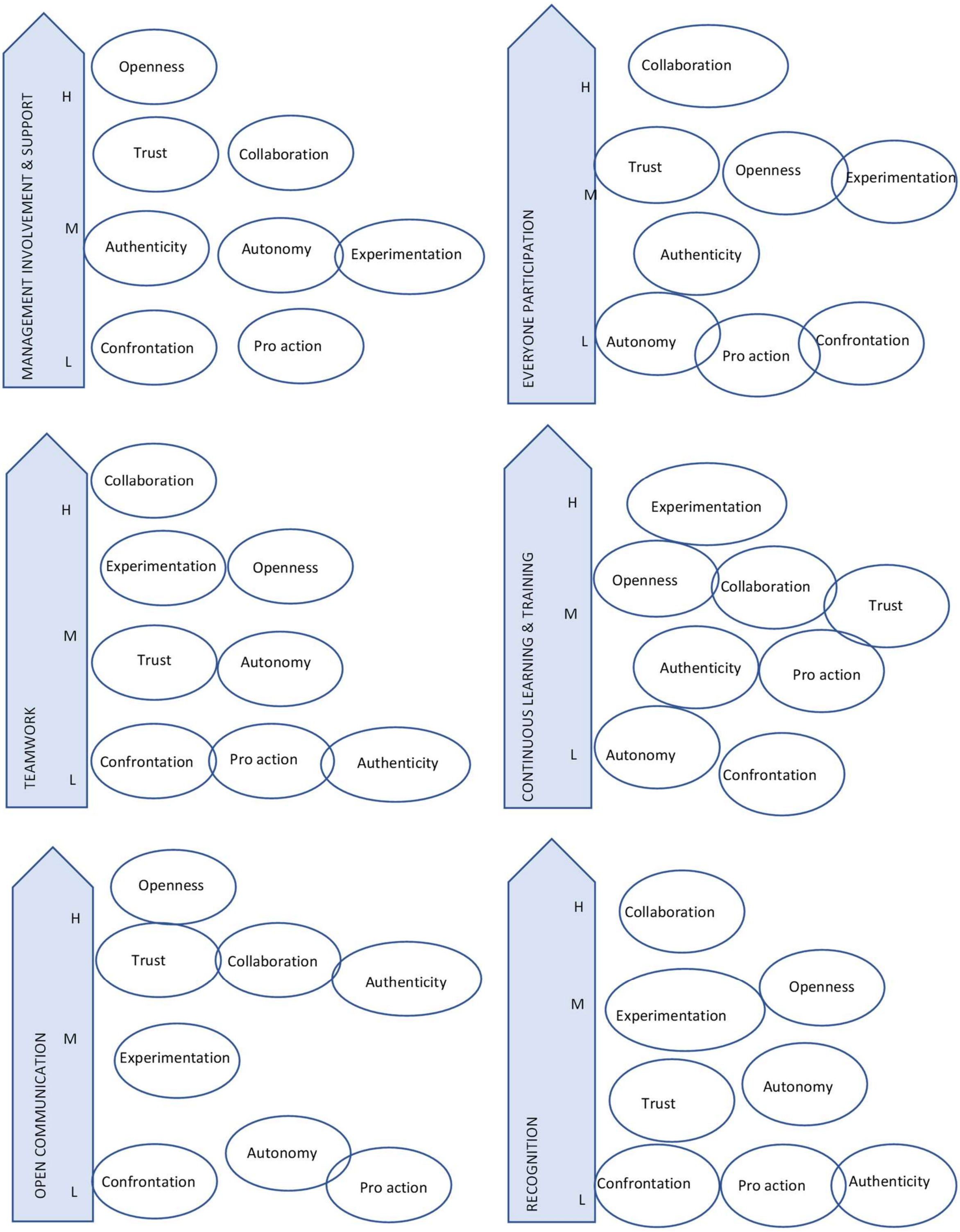

Figure 1. Mapping the contribution of organization values to quality culture

Assessment grid

Based on the above analysis, namely on the results shown in Table 1 and Figure 1, which have pointed out that remote work forms particularly affect collaboration and openness and that those two

OCTOPACE dimensions strongly contribute to the TQM values of employee participation, teamwork, and recognition, the following critical points need to the addressed if a TQM culture is to be maintained and promoted in a remote work environment:

- Increase free interaction among employees;
- Foster open communication between leaders and employees;
- Improve information sharing;
- Enhance employees' participation in setting organizational goals;
- Create a team spirit among organizational members that work at different locations;
- Encourage teamwork and recognize team achievements;
- Cultivate leadership role models to inspire trust;
- Offer help and assistance to employees during periods of crisis or high uncertainty.

These points roughly correspond to possible ways to operationalize the organizational values that have more impact on the creation of a TQM culture and that are also being more threatened by the shift to remote working forms – collaboration, openness, and, to a lower extent, trust.

The grid below might be used to systematize and assess the organization's efforts to address these factors when adopting remote work models. For illustration purposes, Table 2 shows an example of how it can be filled.

Table 2 – Excerpt of the assessment grid

Challenges to be addressed	Priority level (according to the impact of the current level of remote work in the organization)	Potential solutions/mechanisms	Implementation Status		
			Fully Implemented	Partially Implemented	Not Implemented
Increase free interaction among employees	High	Organize a face-to-face team building event	✓		
		Set up a quality circle with periodic online meetings			✓
		Use appropriate body language in face-to-face communication		✓	

Organizations might fill out this grid based on the perceptions of human resource managers and quality managers in strict collaboration. The effectiveness of potential solutions and mechanisms proposed should be assessed by monitoring the level of assimilation of the TQM values they intend to develop by mitigating the negative effects of remote work.

CONCLUDING REMARKS

Over the last decades, several frameworks have been proposed in the literature to characterize organizational cultures. The values that typically form a TQM culture have also been the focus of some papers. More recently, extensive research has been dedicated to the study of the implications of remote work both in organizational performance and employees' satisfaction. Yet, to the author's best knowledge, this is the first systematic attempt to identify, with reference to the OCTAPACE model, the values that might be particularly affected by remote work and to assess how they are likely to impact the development of a Quality Culture.

Even if the current paper is essentially conceptual, it is possible to derive from the analysis conducted, some managerial implications.

Firstly, when reflecting upon the consequences of remote work on the employees' well-being and satisfaction, as well as upon the effects of working away from the office on the way organizations operate, it becomes evident that the frequency of home-based teleworking is an essential factor. In fact, if employees work remotely only a couple of days a week or they do it intensively for a short period of time many of the negative effects are minimized and, most likely, the benefits of this flexible work arrangement override its disadvantages. Therefore, it is possible to argue that hybrid forms of work are superior to pure remote forms, and employees should be required to be at the office on a regular basis.

Another important implication relates to the type of leadership that is more effective to ensure that a TQM culture is implemented and disseminated in a remote work setting. Leaders are expected to use less formal forms of communication and should be relationship-oriented (rather than task-oriented) (de Vries, Tummers and Bekkers, 2019).

This paper contributes to the literature by shedding some light on the organizational values that are particularly impacted by remote working forms. Yet, because it is mainly a conceptual paper, the proposed framework needs to be empirically validated in future studies. Future research aimed at validating this model is expected first to involve a panel of experts and then the administration of a questionnaire survey to HR managers and QM managers of a sample of organizations from different sectors.

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REFERENCES

Ababneh, O. M. A. (2020) 'The impact of organizational culture archetypes on quality performance and total quality management: the role of employee engagement and individual values', *International Journal of Quality and Reliability Management*, 38(6), pp. 1387–1408.

Akemu, O. and Abdelnour, S. (2020) 'Confronting the Digital: Doing Ethnography in Modern Organizational Settings', *Organizational Research Methods*, 23(2), pp. 296–321.

Asatiani, A. *et al.* (2021) 'Constructing continuity across the organisational culture boundary in a highly virtual work environment', *Information Systems Journal*, 31(1), pp. 62–93.

Baruch, Y. (2001) 'The status of research on teleworking and an agenda for future research', *International Journal of Management Reviews*, 3(2), pp. 113–129.

Bathini, D. R. and Kandathil, G. M. (2020) 'Bother me only if the client complains: control and resistance in home-based telework in India', *Employee Relations*, 42(1), pp. 90–106.

Dimitrantzou, C. *et al.* (2021) 'The role of organisational culture in total quality management adoption and cost of quality', *Total Quality Management and Business Excellence*, 0(0), pp. 1–19.

Feldman, S. P. (1986) 'AN ESSAY O N T H E RELEVANCE OF C U L T U R E TO T H E', *Journal of Management Studies*, 23(6), pp. 587–607.

Gambi, L. D. N. *et al.* (2015) 'The relationship between organizational culture and quality techniques, and its impact on operational performance', *International Journal of Operations and Production Management*, 35(10), pp. 1460–1484.

Gimenez-Espin, J. A., Jiménez-Jiménez, D. and Martínez-Costa, M. (2013) 'Organizational culture for total quality management', *Total Quality Management and Business Excellence*, 24(5–6), pp. 678–692.

Giorgi, S., Lockwood, C. and Glynn, M. A. (2015) 'The Many Faces of Culture: Making Sense of 30 Years of Research on Culture in Organization Studies', *Academy of Management Annals*, 9(1), pp.

1–54.

Hildebrandt, S. *et al.* (1991) 'Quality culture and TQM', *Total Quality Management*, 2(1), pp. 1–16.

Hilman, H., Ali, G. A. and Gorondutse, A. H. (2020) 'The relationship between TQM and SMEs' performance: The mediating role of organizational culture', *International Journal of Productivity and Performance Management*, 69(1), pp. 61–84.

Hofstede, G. (1980) 'Culture and Organizations', *International Studies of Management & Organization*, 10(4), pp. 15–41.

Hofstede, G. (2011) 'Dimensionalizing Cultures: The Hofstede Model in Context', *Psychology and Culture*, 2(1).

Kanji, G. K. and Yui, H. (1997) 'Total quality culture', *Total Quality Management*, 8(6), pp. 417–428.

Kuo, T. H. and Kuo, Y. L. (2010) 'The effect of corporate culture and total quality management on construction project performance in Taiwan', *Total Quality Management and Business Excellence*, 21(6), pp. 617–632.

van Muijen, J. J. and al, et. (1999) 'Organizational Culture: The Focus Questionnaire', *European Journal of Work and Organizational Psychology*, 8(4), pp. 551–568.

Oshri, I., Kotlarsky, J. and Willcocks, L. P. (2007) 'Global software development: Exploring socialization and face-to-face meetings in distributed strategic projects', *Journal of Strategic Information Systems*, 16(1), pp. 25–49.

Palumbo, R. (2020) 'Let me go to the office! An investigation into the side effects of working from home on work-life balance', *International Journal of Public Sector Management*, 33(6–7), pp. 771–790.

Palumbo, R., Manna, R. and Cavallone, M. (2020) 'Beware of side effects on quality! Investigating the implications of home working on work-life balance in educational services', *TQM Journal*. doi: 10.1108/TQM-05-2020-0120.

Patyal, V. S. and Koilakuntla, M. (2018) 'Impact of organizational culture on quality management practices: an empirical investigation', *Benchmarking*, 25(5), pp. 1406–1428.

Powell, T. C. (1995) 'Total Quality Management as competitive advantage : a review and empirical study', *Strategic Management Journal*, 16, pp. 15–37.

Quinn, R. and Rohrbaugh, J. (1981) 'A Competing Values Approach to Organizational Effectiveness', *Public Productivity Review*, 5(2), pp. 122–140.

Robbin, S. (2004), Organizational Behavior, 11th ed., Prentice-Hall, Upper Saddle River, NJ.

Schein, E. H. (2010). Organizational culture and leadership. San Francisco, CA: Jossey-Bass.

Sinclair, J. and Collins, D. (1994) 'Towards a Quality Culture?', *International Journal of Quality & Reliability Management*, 11(5), pp. 19–29.

Sinha, N. and Dhall, N. (2020) 'Mediating effect of TQM on relationship between organisational culture and performance: evidence from Indian SMEs', *Total Quality Management and Business Excellence*, 31(15–16), pp. 1841–1865.

Viljoen, S. J. and Van Waveren, C. C. (2008) 'An improved model for quantifying an organisational quality culture', *PICMET: Portland International Center for Management of Engineering and Technology, Proceedings*, (c), pp. 1781–1789.

de Vries, H., Tummers, L. and Bekkers, V. (2019) 'The Benefits of Teleworking in the Public Sector: Reality or Rhetoric?', *Review of Public Personnel Administration*, 39(4), pp. 570–593.

Wu, S. J., Zhang, D. and Schroeder, R. G. (2011) 'Customization of quality practices: The impact of quality culture', *International Journal of Quality and Reliability Management*, 28(3), pp. 263–279.

Sustainable Management in the hotel sector: an exploratory study

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ABSTRACT

Tourism activity increasingly occupies a position of great scale regarding the sector that moves the world economy the most. However, there are several challenges that this sector faces in Portugal, subjecting it to great vulnerability, from the seasonality of the business, environmental issues, job insecurity, lack of qualified professionals, etc. Currently, there is a growing concern about the preservation of the environment, social inequalities, and the disparity of wealth distribution that forced the United Nations to challenge the world with the 2030 agenda and the SDGs to which the tourism sector cannot remain indifferent.
Purpose - Thus, this work intends to start research about the impact of management systems as sustainability support in this activity, identifying the existing practices.
Design/methodology/approach - For the development of the research method, five hotel resorts were selected, which responded to a survey, as a way to assess the research instrument to be replicated a posteriori on a broader basis. The questions were built based on the current literature review to understand how management systems and sustainability are represented in Portugal.
Findings - Through the collection, analysis, and processing of the results obtained, there is a low tendency to implement management systems, due to factors such as the associated cost and the concern for a return only in the long term and because they do not feel that individual clients are demanding these systems. On the other hand, they believe that they are an asset for the effective management of the hotel. Regarding the issue of sustainability, the trend is growing and there are already hotel developments that have

implemented sustainable practices. However, the financial return is only achieved in the medium to long term, which is the main reason why the hotel management does not want to move forward with this responsibility.
Practical implications - To characterize the hotel sector and its relationship with management systems. To research and collect good practices to be implemented in any type of organization, regardless of its size. Through the creation of new strategies leveraged on excellence models, promoting the use of management systems, to achieve the three pillars of sustainability (economic, social, and environmental dimensions).
Value- A new vision of improvement of its management at all levels, also translating into financial benefits, which may lead the sector to search for more on this theme, thus translating into a new approach of effective and continuous management for this sector. Help the hotel industry to engage the United Nations SDGs.
Keywords -Management systems; Hotel sustainability; Hotel developments; Sustainable practices

INTRODUCTION

Recently, organizations, whether in the public or private sector, have highlighted a high level of concern regarding sustainability, intending to be able to transmit to future generations the current world in which we live.

Considering marketing, an essential sales tool for a product and/or service, it is possible to evaluate this issue in the hotel industry. Since there is a wide range of platforms (booking, Google, TripAdvisor, among others), that allows a customer to make a sustainable preference through a wide range of hotel units, where numerous comments and ratings of each hotel unit are reproduced, this aspect translates into the current digital transformation that the industry has.

Sustainability is a topic that has long been discussed and addressed by major world entities, and there are several examples of this, such as the UN - United Nations Organization. The global pact, in the year 2000, launched by Koffi Annan stated "I propose that you, the business leaders... and we, the United Nations, initiate a global compact shared values and principles, which will give a human face to the global market", thus giving rise to the ten fundamental principles through the global pact that is developed steps/challenges/objectives/goals to address the social, environmental and economic adversities, currently summarized in the 17 SDGs - sustainable development goals, which are part of the 2030 Agenda.

This action led ISO (International Organization for Standardization) to develop and update its management systems aligning them with the SDGs. Thus, contributing to the path of sustainability in organizations. Quoting, "ISO is built around a spirit of collaboration and believes that standardization plays a key role in transforming our world, into a more sustainable world." (ISO - Strategy 2030, n.d.).

The tourism sector is one of the fastest-growing industries in the world, and especially in developing countries and regions, has not been indifferent to this issue. Since the 1970s, tourism has brought considerable pressure in terms of its impacts on the natural, cultural and social environments (UNEP and UNWTO, 2005).

Knowing that sustainability is the capacity to satisfy our needs in the present without compromising the capacity of future generations to satisfy their own needs, this work intends to start exploratory research on the impact of management systems as a support for sustainability in this activity, identifying existing practices.

LITERATURE REVIEW

Sustainable development and management systems

Sustainability is a term that has long been known and debated but has gained great importance in industry and people's daily lives. Thus, the term sustainable development is already referred to before the 2000s, when a 'global agenda for change' was convened in the mid-1980s, seeking to meet the needs and aspirations of the present without compromising the ability to meet those of the future. Long-term environmental strategies were developed up to the year 2000, resulting in cooperation between developing countries at their different stages of development, whether in economic, social, or environmental terms (Commission on Environment, n.d.).

In essence, the important thing was to create a basis of common objectives and mutual support, taking into account the various variables, people, resources, environment, and development, for a better future for a world community.

Sustainability requires visions of human needs and well-being that incorporate non-economic variables such as education and health enjoyed for its own sake, clean air and water, and the protection of natural beauty. It must also work to remove the disabilities of disadvantaged groups, many of whom live in ecologically vulnerable areas (Commission on Environment, n.d.).

No single model of sustainability will be found, as economic and social systems and ecological conditions differ widely between countries. Each nation will have to work out its concrete policy implications. However, regardless of these differences, sustainable development must be seen as a global objective.

Although the first wave of sustainable development began long ago, it has not been easy for corporate businesses to understand, let alone comply with, sustainability practices (Baker, 2005).

Also, several studies point out that the more an organization values economic and social issues, the faster they are interested in implementing sustainability. What through the appreciation of the environment, does not translate into the same willingness to invest in sustainability, which leads to the conclusion that sustainability is driven by social and economic issues (Saunila, Ukko, and Rantala, 2018).

Sustainable management activities focus on creating efficiency and value for organizations. Scholars argue that assessing and enabling appropriate management interventions can pave the way for future competitive advantage and sustainability (Cormican *et al.*, 2021).

Many models, methods, and tools can help an organization implement and/or create a commitment to sustainability. To support today's businesses with the complexity of the social, environmental, market, and technological trends, International Standards can help businesses prosper and grow while solving some of the world's biggest challenges and making a real difference on our planet (ISO - Sustainability, n.d.).

And so, the management systems, emerged as a way to assist the continuous improvement of organizations, collaborating to the formation of a structure that contributes to the management of a specific area (Poltronieri *et al.*, 2017).

Through the implementation and certification of management systems, the adoption of sustainability practices is encouraged, promoting a voluntary approach, which includes, measures, and reports good practices in the social, environmental, and economic dimensions of sustainability. The main management systems, which fall under these dimensions, are ISO 9001 - Quality Management Systems (economic), ISO14001 - Environmental Management Systems (environmental), and ISO 45001 - Occupational Health and Safety Management System (social).

The integration of these management systems increases the ability of companies to achieve sustainability (Boronat-Navarro and Pérez-Aranda, 2020).

The number of companies applying for an ISO certificate has grown consistently in recent decades, with some authors arguing that external certificates related to quality management improve the economic performance of the company, but when the decision is made, management should be aware of the time it requires and the important amount of resources, financial and human, that are needed (Han *et al.*, 2011).

Obtaining an ISO certificate is a resource-consuming process. When companies are asked why these or similar certificates and processes are not implemented, they argue lack of information, cost issues, and lack of resources as the main reasons (Tang and Lam, 2017).

Sustainable management in the hotel sector

Since 1960, the hotel industry has used sustainability as a pillar to mitigate the environmental and social impacts arising from the activity, due to the consumption of natural resources, its effect on the environment, and its economic and social impact on the communities where such establishments are located (Shanti, 2016),(Mihalič, Žabkar, and Cvelbar, 2012).

Thus, the concept of a sustainable hotel emerges which is defined as a managed entity with various socio-economic and environmental management attributes. By incorporating the notion of sustainable building, these hotels offer eco-friendly products and services to consumers (Mousavi, Hoşkara, and Woosnam, 2017).

According to studies the sustainability approach by hotels is used as part of their economic strategy, to obtain competitive advantages, and cost optimization, by reducing energy and water consumption, is often neglected, social and environmental protection (Girard and Nocca, 2017).

The effective approach to sustainability, relies on the balance of its three aspects (economic, social, and environmental), being a challenge for the hotel sector since the results are only visible in the long term and the customer is not always willing to pay the value that this practice entails (Mousavi et al., 2017), (Tang & Lam, 2017).

The hotel sustainability may translate into high initial costs, however, it increases the brand value, which should be disseminated through marketing actions of these practices, seeking a more environmentally responsible target audience, who is willing to pay more for this type of hotel (Boronat-Navarro and Pérez-Aranda, 2020). Hotel websites and media have a huge potential to communicate these products and services effectively and foster the relationship with their customers, increasing their satisfaction level (Li, Wang, and Yu, 2015) leading to the economic profitability of the hotel (Khatter *et al.*, 2019).

However, some hotels implement environmental practices as a marketing strategy, considered false, only to attract new customers (Lyon and Montgomery, 2015).
The implementation of sustainable practices is mostly implemented and shared by large multinational hotel companies, "receiving guidance from their parent company on their commitment to sustainability" (Khatter *et al.*, 2019).
With small hotel developments, the implementation of practices is not as visible, for internal reasons such as lack of skills, resources, and the associated costs. This leads to the fact that they often do not feel the "need to address environmental sustainability issues" (Burrows & Rich, 2016), (Hillary, 2004) . Furthermore, there are external reasons for not feeling the need to implement practices, such as low pressure from customers, stakeholders, and other motivators.
Studies report that environmental reporting by hotels is a challenge for many and there is a particular need for smaller hotels to embrace sustainability to keep pace with their larger counterparts (Chan, 2010).
The implications of not undertaking sustainability actions lie in the fact that in the coming years, guests are likely to become more environmentally aware and educated, and may base their decisions to stay at a hotel based on its sustainability policy, along with other factors they consider when making their choice (Khatter *et al.*, 2019).
Thus, it is possible to realize that larger hotel chains implement sustainable practices more quickly than smaller hotels, however, from the moment they understand that the implementation of such practices translates into profitability benefits, even if in the long term (Doppelt and McDonough, 2017) and a positive image, sustainable practices will be more widely adopted by hotels. Hotels that do not heed this message run the risk of losing market share and reputational damage (Carroll and Shabana, 2010).
Certification is a way of offering more information, transparency, and credibility about the practices of organizations, guaranteeing quality and reliability.
To enable sustainable management in the hospitality sector, the International Organization for Standardization developed ISO 21401:2018 which refers to sustainability management systems for accommodation establishments. The document addresses the environmental, social, and economic requirements for the implementation of a sustainability management system for this sector, is applied to any type of accommodation, regardless of its typology, size, or location, and has as objectives the implementation, perseverance, and improvement of sustainable practices in its processes, ensuring compliance with the defined sustainability policy (APCER - The ISO 21401

Standard For Sustainable Hotels - A Modern and Current Vision, n.d.), (ISO - ISO 21401:2018 - Tourism and Related Services - Sustainability Management System for Accommodation Establishments - Requirements, n.d.).

Thus, taking into account the existence of the aforementioned standard, this translates into the integration of standards 9001/14001/45001, on the issue of sustainability, into a single one and focusing on the hotel sector. Also, it should be noted that all the management systems mentioned, including 21401:2018, follow the same structure, called Annex SL, however, ISO 21401:2018 is geared toward the hospitality sector. (ISO/IEC Directives, Part 1 — Consolidated ISO Supplement — Procedures for the technical work — Procedures specific to ISO, 2022)

RESEARCH METHODOLOGY

This paper presents applied research through an exploratory study with procedures of an experimental investigation, serving as the basis for a research instrument for the Delphy methodology, to validate the proposed approach from a practical and conceptual point of view. In the following scheme (figure1) the key steps for conducting the present investigation are presented.

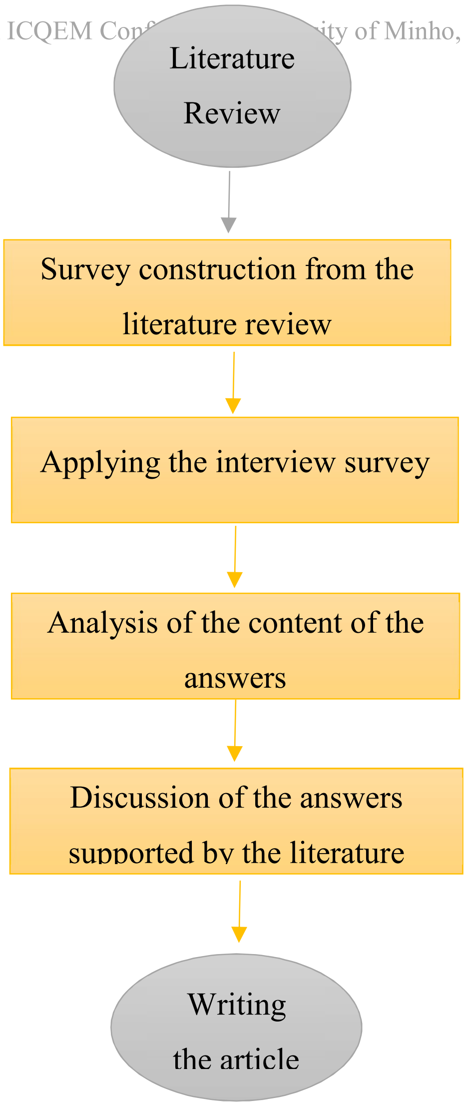

Figure 1 - Key steps for investigation

Source: Elaborated by the authors

A literature search was used to ground the study and construct the interviews and surveys, applied to the target audience, in a manner aligned to the objective, with the concern of highlighting real problems to put into a discussion with people from the area.

In the first stage, the questionnaire was validated through interviews with four hotel managers from Portugal, regardless of the region. The main objective of this first stage was to identify possible difficulties with the interpretation of the questions and thus fine-tune or eliminate those questions. In the final stage, the surveys were sent to five selected properties.

The questions were built based on the current literature review, to understand how management systems and sustainability are represented in the hotel sector in Portugal, and also, to facilitate the reading of the results, the interview and survey questions were

grouped by sections, as presented in table 1. The survey, with 11 questions, was designed to identify the gaps in the hotel sustainability management model.
The results were organized by content analysis, to indicate the trends of the theme for the sector, and proposals supported by the literature were presented.

Table 1 - Survey for the hotel sector based on the literature review

Section	Interview questions	Question of Inquiry	Authors Association
Covid-19 vs Hotel Sustainability	1 - What is the main challenge in the tourism/hotel industry before and after the pandemic? With the current pandemic situation, do you think there has been more concern for sustainable issues?	1- Are there challenges in the tourism/hotel industry before and post-pandemic? 2- If you answered yes, identify at least one challenge. 3- With the current pandemic situation, do you think there has been more concern about sustainable issues?	The tourism industry in adaption to the covid-19 pandemic: the case of team building activities of the SMEs, n.d.)
Importance of sustainability in the hospitality	2 - Do you consider sustainability (economic, social, and environmental) relevant in the hotel sector?	4- Do you consider sustainability (economic, social, and environmental) relevant in the hotel sector? And why?	(Mihalič, Žabkar and Cvelbar, 2012)
	3 - What value does the hotel sector place on the issue of sustainability?	5- What value does the hotel sector or the hotel unit to which you belong place on the question of sustainability?	(Mihalič, Žabkar and Cvelbar, 2012) (Mousavi, Hoşkara and Woosnam, 2017)
	4 - What are the social, environmental, and economic problems affecting the tourism/hotel sector?	6- What are the social, environmental, and economic problems affecting the tourism/hotel sector? 7- Identify one or more problems (social, environmental, and economic) affecting the sector.	(Mousavi, Hoşkara and Woosnam, 2017)
Sustainable hotel - Practices	5 - Do you believe that the concept of a "sustainable hotel" can increase market	8- Do you believe that the concept of a "sustainable hotel" can increase growth in the market? And in what way?	(Mousavi, Hoşkara and Woosnam, 2017) (Tang and Lam, 2017)

	growth? And in what way?		
	6 - Can you list three sustainability practices (economic, social, and environmental) implemented or that could be implemented by the organization and that have been successful in the European Community recommendations?		(Weerathunga *et al.*, 2020) (Bacari, Séraphin and Gowreesunkar, 2020) (Alameeri *et al.*, 2018)
Hotel Management	7 - Can leadership, people management, and focus on stakeholders affect the company's competitive position?		(Pereira-Moliner *et al.*, 2012)
	8 - Do you agree that management systems can be an added value for the sector?		(Boronat-Navarro and Pérez-Aranda, 2020)
	9 - Do you believe that the SG has a positive effect on the sustainable performance of the hotel sector?		(Pereira-Moliner *et al.*, 2012)
	10- Are you aware of the existence of excellence models for the sector, such as the EFQM?		(Sila and Ebrahimpour, 2004)
	11 - In your opinion would it be advantageous to implement a management system (e.g. ISO 9001, 14001, 45001) or a model of excellence?		(Benavides-Velasco, Quintana-García and Marchante-Lara, 2014)

Source: Elaborated by the authors

RESULTS AND DISCUSSION

As previously mentioned in the methodology, questions were asked to four hotel managers, to refine the questions for the final questionnaire, to be perceptible, and make clear the objective of each question. Therefore, with the updating of the questions and to allow a good reflection of the results, sections were defined, as shown in table 1.

Covid-19 vs sustainability

Respondents report that there were challenges before and after the pandemic. The main challenge before the pandemic was the lack of manpower.

After the pandemic, the issue of (re)hiring qualified human resources remains a challenge for the hospitality industry. However, the pandemic has added other challenges to the sector, such as the hygienist of spaces, the use of protective equipment, the non-profitability of spaces, and their associated double costs.

However, according to the respondents, most of them consider that there has been a growing concern with sustainability on the part of companies and clients, mainly in terms of social and economic issues and, to a lesser extent, in the search for good practices in Tourism or day-to-day life.

As stated by the author (Pinto Borges, 2021) the tourism industry, suffers some damage through natural disasters, as well as by unexpected events, which was the case of covid-19, which led to economic stagnation and now recently with the reduction of covid cases the issue of rehiring human resources has experienced some difficulties.

Importance of sustainability in the hospitality

Regarding the relevance and valuation that the hotel sector has in terms of sustainability, the respondents state that it is of high importance, since it brings competitive advantages, and there is also the awareness that resources are finite, and hence they value resource management. Thus, corroborating with the statement of the author Girard and Nocca, 2017 this indicates that the approach of sustainability is used as part of the economic strategy of hotels, to obtain competitive advantages. Having the knowledge that people are entitled to their rights and knowing that we are a service-oriented country and that the tourism sector represents a good part of the GDP (gross domestic product)

They still refer that Portugal is a step behind other countries when it comes to sustainability. However, new investors in this sector, when planning their developments, already include sustainability actions, which, in turn, in hotels with older infrastructures, the issue of implementing sustainable practices is worrying because it implies higher investments.

They believe that the factor of the hotel units feeling that sustainability is relevant and is valued can be a differentiating step so that their stakeholders can feel it too, even though there is already a high number of customers/employees who are already aware that one should be sustainable in their daily lives.

In terms of the issues that directly affect the hotel sector, the three aspects (social, economic, and environmental) were identified, but with a greater focus on social aspects. Taking into account the literature and the author (Girard and Nocca, 2017), the survey results disagree with his statement, and according to him, the social and environmental issue is often neglected, and according to the results, the social issue is taken into great consideration.

Thus, the lack of qualified labor was again mentioned, adding that the sector does not have unions that exert governmental pressure to improve the working conditions of its employees, that they consider being penalized when compared to other industries, and that, for this reason, it is considered an urgent issue.

At the environmental level, climate change is identified as a problem for the sector, being one of the sectors that besides being a "victim" of this problem, is also the sector that contributes the most to the carbon footprint, thus to the increase of these changes. Still, on environmental issues, they add that the inflated cost of resources/raw materials is a barrier for the sector.

About the economic aspect, they mention as a problem the increase in the cost of living, reduced salaries, investments in technologies, and the lack of allowances, translating into financial difficulties, which involves a reduced rate of guests.

Sustainable hotel - practices

The revelation of the concept of "sustainable hotel" through the respondents, resulted in the positive affirmation, that this concept brings with it a competitive advantage for them, in the sense that, people already have this concern, that at the time of selecting a destination or hotel, their choice leans towards sustainable units.

However, respondents reveal some difficulty in implementing sustainable actions in more urban areas, although they add that it is not impossible. They also reflect the fear that if the added value is not visible or proven, the adhesion of customers may be reduced.

They add, that the factor of a hotel being sustainable is a turning point to attract more customers, who are more involved in these issues and a way to raise the awareness of those less informed about this subject, towards an attitude generating attitude, so that it becomes a cycle and becomes daily care of all.

Thus, these results corroborate what the author Boronat-Navarro and Pérez-Aranda (2020), states when they refer that there is no pressure from customers for the implementation of the practices, which generates low customer adherence. Still, Lyon and Montgomery (2015) confirm that sustainable practices are a way to attract new customers.

Sustainability practices resulting from the tourism developments were identified, which claim to be an added value, in the sense that the investment pays off, since in the reduction of consumption they have gains, however, the initial investment may not be seen with good eyes by all. Proving the statement of Doppelt, B., and McDonough, W. (2017), "such practices translate into profitability benefits, even if in the long term".

Thus, some practices mentioned by hotel units are:

Environmentally: Recycling in all areas; presence sensors; tap water reducers; rainwater retention systems; biological gardens; solar panels; use of LED lights; controlled irrigation system; free parking and charging for electric vehicles; elimination of plastic

On a Social level: support of local and national associations (customer comments turn into monetary value); donation of materials (mattresses, old clothes, TVs); sponsorship of local events; promotion of the purchase of local products to support the local community; food donations; cleaning of woods and beaches; professional qualification.

On an economic level: cautious investments; contribution to the local economy; purchase of recycled goods; selection of local suppliers; tax incentives for companies aiming at sustainable development

Hotel management

Regarding hotel management, respondents believe that leadership, human resource management, and focus on stakeholders are considerable aspects that affect the competitive position of hotels.

Concerning the questions of whether respondents know and feel that it is advantageous to implement management systems and/or excellence models, their knowledge of management systems is noted, whereas about excellence models this knowledge is not so present/discussed within this sector.

Therefore, all respondents revealed that the issue of management systems implementation and management models are an added value for the sector. They mention that it is necessary to verify which existing models translate into advantages for the hotel industry, depending on the strategic objectives of the hotels. They also add, those management systems such as NP EN ISO 9001/14001/45001 are generic models, but that can add value to their hotel units, and in turn have a positive effect on the sustainable performance of hotel units, as stated by Boronat-Navarro and Pérez-Aranda (2020), who argue that the integration of management systems increase the ability of companies to achieve sustainability.

And the one that would make the most sense to be implemented, in this context of sustainable hotel management, would be ISO 21401:2018 which is directed to the issue of sustainable hotels.

The respondents pointed out that the implementation of these management models is something costly and laborious, and that many hotel units do not have the capacity, either in human or financial resources, to bear these costs. And for such implementation to be carried out, support is necessary. Thus, as he states Han et al., 2011 when deciding to implement/certify a company, it is necessary to be aware of the time it will require, as well as the importance of the financial and human resources that will be necessary.

CONCLUSION

This work intends to start research on the impact of management systems as a support for sustainability in this activity, identifying the existing practices.

Through the collection, analysis, and treatment of the results obtained, there is a low tendency to implement management systems (quality, environment, and safety), due to factors such as the associated cost and not feeling their demand from customers. They consider these systems to be generic models, but that they can add value to their hotel units, and in turn have a positive effect on sustainable performance. However, they also state that the implementation of these systems is excessively expensive and only brings returns in the long term.

On the issue of sustainability, the trend is growing and there are already hotel developments that have implemented sustainable practices.

The new ISO 21401:2018 - Tourism and related services - Sustainability management system for accommodation establishments - Requirements, specifying, will perhaps assist implementation, more focused on sustainability practices in this sector.

In this study, some practices used have already been evidenced, such as:

- Environmentally: Recycling in all areas; presence sensors; tap water reducers; rainwater retention systems; biological gardens; solar panels; use of LED lights; controlled irrigation system; free parking and charging for electric vehicles; elimination of plastic
- social level: support of local and national associations (customer comments turn into monetary value); donation of materials (mattresses, old clothes, TVs); sponsorship of local events; promotion of the purchase of local products to support the local community; food donations; cleaning of woods and beaches; professional qualification.

- economic level: cautious investments; contribution to the local economy; purchase of recycled goods; selection of local suppliers; tax incentives for companies aiming at sustainable development

This study also concluded that hotel units are more aware of sustainable development issues, as a cost reduction tool and consumers are increasingly aware of these types of practices, which may influence their choice.

LIMITATIONS

As this is exploratory research, the sample size is small, but it shows the trends of sustainability management in this sector through the perception of its managers.

FUTURE RESEARCH DIRECTIONS

With a view to future research, it is suggested to deepen the questions to other hotel units, taking into account that the sample of this study is reduced and presents a low result of the representativeness of hotel units in Portugal. These interviews serve as a basis for applying the Delphy methodology to about 12 experts in the field, such as professionals from the hospitality industry, academia, and the public sector.

In addition to increasing the sample for the study of this theme, and with the identification of the new ISO 21401 standard, future studies are designed to verify the implementation of the standard and whether it meets the expectations of the sector.

REFERENCES

Alameeri, A. *et al.* (2018) "Sustainable management practices in UAE hotels," *International Journal of Culture, Tourism, and Hospitality Research*, 12(4), pp. 440–466. doi:10.1108/IJCTHR-10-2017-0100/FULL/PDF.

APCER - A norma ISO 21401 para Hotéis Sustentáveis - uma visão moderna e atual (no date). Available at: https://www.apcergroup.com/pt/newsroom/1807/a-norma-iso-21401-para-hoteis-sustentaveis-uma-visao-moderna-e-atual (Accessed: April 13, 2022).

Bacari, C., Séraphin, H. and Gowreesunkar, V.G.B. (2020) "Sustainable development goals and the hotel sector: case examples and implications," *Worldwide Hospitality and Tourism Themes*, 13(1), pp. 9–21. doi:10.1108/WHATT-08-2020-0085/FULL/PDF.

Baker, S. (2005) “Sustainable development,” *Sustainable Development*, 9780203495933, pp. 1–245. doi:10.4324/9780203495933.

Benavides-Velasco, C.A., Quintana-García, C. and Marchante-Lara, M. (2014) “Total quality management, corporate social responsibility and performance in the hotel industry,” *International Journal of Hospitality Management*, 41, pp. 77–87. doi:10.1016/J.IJHM.2014.05.003.

Boronat-Navarro, M. and Pérez-Aranda, J.A. (2020) “Analyzing willingness to pay more to stay in a sustainable hotel,” *Sustainability (Switzerland)*, 12(9), pp. 1–17. doi:10.3390/su12093730.

Burrows, R. and Rich, Dr.S.R. (2016) “Hotelier Attitudes toward Sustainability in Virginia Beach,” *Travel and Tourism Research Association: Advancing Tourism Research Globally* [Preprint]. Available at: https://scholarworks.umass.edu/ttra/2012/Visual/7 (Accessed: April 13, 2022).

Carroll, A.B. and Shabana, K.M. (2010) “The Business Case for Corporate Social Responsibility: A Review of Concepts, Research and Practice,” *International Journal of Management Reviews*, 12(1), pp. 85–105. doi:10.1111/J.1468-2370.2009.00275.X.

Chan, E.S.W. (2010) “Implementing Environmental Management Systems in Small- and Medium-Sized Hotels: Obstacles:” *http://dx.doi.org/10.1177/1096348010370857*, 35(1), pp. 3–23. doi:10.1177/1096348010370857.

Commission on Environment, W. (no date) “Report of the World Commission on Environment and Development: Our Common Future Towards Sustainable Development 2. Part II. Common Challenges Population and Human Resources 4.”

Cormican, K. *et al.* (2021) “Towards Sustainable Knowledge Sharing Practices: An Analysis of Organizational Level Enablers,” *Sustainability 2021, Vol. 13, Page 12934*, 13(23), p. 12934. doi:10.3390/SU132312934.

Doppelt, B. and McDonough, W. (2017) “Leading Change Toward Sustainability : A Change-Management Guide for Business, Government and Civil Society,” *Leading Change Toward Sustainability* [Preprint]. doi:10.4324/9781351278966.

Han, H. *et al.* (2011) “Are lodging customers ready to go green? An examination of attitudes, demographics, and eco-friendly intentions,” *International Journal of Hospitality Management*, 30(2), pp. 345–355. doi:10.1016/J.IJHM.2010.07.008.

Hillary, R. (2004) “Environmental management systems and the smaller enterprise,” *Journal of Cleaner Production*, 12(6), pp. 561–569. doi:10.1016/J.JCLEPRO.2003.08.006.

ISO - Estratégia 2030 (no date). Available at: https://www.iso.org/strategy2030.html (Accessed: April 13, 2022).

ISO - ISO 21401:2018 - Tourism and related services — Sustainability management system for accommodation establishments — Requirements (no date). Available at: https://www.iso.org/standard/70869.html (Accessed: April 13, 2022).

ISO - Sustentabilidade (no date). Available at: https://www.iso.org/news/sustainability.html (Accessed: April 13, 2022).

ISO/IEC Directives, Part 1 — Consolidated ISO Supplement — Procedures for the technical work — Procedures specific to ISO (no date). Available at: https://www.iso.org/sites/directives/current/consolidated/index.xhtml (Accessed: May 12, 2022).

Khatter, A. *et al.* (2019) "Analysis of hotels' environmentally sustainable policies and practices: Sustainability and corporate social responsibility in hospitality and tourism," *International Journal of Contemporary Hospitality Management*, 31(6), pp. 2394–2410. doi:10.1108/IJCHM-08-2018-0670/FULL/PDF.

Li, X., Wang, Y. and Yu, Y. (2015) "Present and future hotel website marketing activities: Change propensity analysis," *International Journal of Hospitality Management*, 47, pp. 131–139. doi:10.1016/J.IJHM.2015.02.007.

Lyon, T.P. and Montgomery, A.W. (2015) "The Means and End of Greenwash:" *http://dx.doi.org/10.1177/1086026615575332*, 28(2), pp. 223–249. doi:10.1177/1086026615575332.

Mihalič, T., Žabkar, V. and Cvelbar, L.K. (2012) "A hotel sustainability business model: Evidence from Slovenia," *Journal of Sustainable Tourism*, 20(5), pp. 701–719. doi:10.1080/09669582.2011.632092.

Mousavi, S.A., Hoşkara, E. and Woosnam, K.M. (2017) "Developing a model for sustainable hotels in Northern Cyprus," *Sustainability (Switzerland)*, 9(11). doi:10.3390/SU9112101.

Pereira-Moliner, J. *et al.* (2012) "Quality management, environmental management and firm performance: direct and mediating effects in the hotel industry," *Journal of Cleaner Production*, 37, pp. 82–92. doi:10.1016/J.JCLEPRO.2012.06.010.

Pinto Borges, Ana. (2021) "Proceedings of the International Workshop Tourism and Hospitality Management (IWTHM2021) 7th of May 2021, Porto, Portugal."

Poltronieri, C.F. *et al.* (2017) "Um instrumento para a avaliação de sistemas de gestão integrados," *Gestão & Produção*, 24(4), pp. 638–652. doi:10.1590/0104-530x1697-14.

Saunila, M., Ukko, J. and Rantala, T. (2018) "Sustainability as a driver of green innovation investment and exploitation," *Journal of Cleaner Production*, 179, pp. 631–641. doi:10.1016/J.JCLEPRO.2017.11.211.

Shanti, J. (2016) "A study on environmental sustainability practices of star hotels in Bangalore," *Asian Journal of Business Ethics*, 5(1–2), pp. 185–194. doi:10.1007/S13520-016-0063-5/TABLES/2.

Sila, I. and Ebrahimpour, M. (2004) "An examination of quality management in luxury hotels," *International Journal of Hospitality and Tourism Administration*, 4(2), pp. 33–59. doi:10.1300/J149V04N02_03.

Tang, C.M.F. and Lam, D. (2017) "The role of extraversion and agreeableness traits on Gen Y's attitudes and willingness to pay for green hotels," *International Journal of Contemporary Hospitality Management*, 29(1), pp. 607–623. doi:10.1108/IJCHM-02-2016-0048/FULL/PDF.

The tourism industry in adaption to the covid-19 pandemic: the case of team building activities of the SMEs (no date). Available at: https://www.researchgate.net/publication/351514537_The_tourism_industry_in_adaption_to_the_covid-19_pandemic_the_case_of_team_building_activities_of_the_SME%27s (Accessed: April 13, 2022).

Weerathunga, P. *et al.* (2020) "Application of Entropy-Based Topics in Analysis of Sustainability Performance of Sri Lanka Hotels," *Journal on Innovation and Sustainability RISUS*, 11(3), pp. 100–108. doi:10.23925/2179-3565.2020v11i3p100-108.

Protocol for refinement and validation of a conceptual model of service quality for Direct-to-Consumer telemedicine consultation

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ABSTRACT

Purpose: A conceptual service quality model for Direct-to-Consumer (DTC) telemedicine consultation was developed based on an extensive literature review of 35 health and 25 e-service quality models. The review was conducted during January-December 2021 and led to the identification of a list of quality dimensions and development of a hierarchical, context-specific service quality model on three primary dimensions (system quality, interaction quality, use quality). The purpose of this study is to establish a Delphi study protocol to verify the validity of the model and identified dimensions of DTC telemedicine's service quality. **Methodology and Findings:** The present article summarized the key aspects of the Delphi technique with an emphasis on the strengths and weakness of this popular consensus method. The proposed conceptual model will be tested through the Delphi technique to validate, add, remove, adapt or refine the identified dimensions using feedback from 10 patients, 10 telemedicine teleconsultants and 3 service quality academics. A maximum of 4 rounds of online questionnaires will be held. Consensus will be considered reached if at least 70% of the participants agree/strongly agree that an item should be included on a 5-point Likert scale, the inter-quartile score is less than 1.0 and the I-CVI is of 0.78 or higher after two rounds. **Value:** A potential limitation of the Delphi technique is the weakness of methodology. The paper provides a clear architecture of the methodology that will be employed by the authors to conduct the Delphi study.

Keywords: Direct-to-Customer (DTC) telemedicine, Service quality, Scale validation, Delphi study.

INTRODUCTION

Researchers devoted considerable attention to the study of service quality, its conceptualization and measurement over the last four decades (Parasuraman, Zeithaml and Malhotra, 2005). The well-known SERVQUAL instrument (Parasuraman, Zeithaml and Berry, 1988) with its five generic dimensions (tangibles, reliability, responsiveness, assurance, empathy) has been widely used in various service environments (Ladhari, 2009). However, concerns have been raised regarding the use of a universal service quality model applicable across all service industries (Carman, 1990; Philip and Hazlett, 1997; Ladhari, 2008). For that reason, several industry-specific scales of service were developed. In previous work conducted by the authors, service quality of DTC telemedicine consultation was investigated. The findings supported this view and demonstrated the need to create a context-specific service quality model to capture the unique characteristics of DTC telemedicine consultations. The results indicated service quality of Direct-to-Consumer telemedicine consultation is interdisciplinary and encompasses generic and context-specific dimensions from the health, e-service quality and information system literature. A hierarchical service quality model on three primary dimensions emerged from the previous exploratory research and literature review carried out.

The proposed conceptual service quality model for DTC telemedicine consultation from a patient's perspective includes 3 primary dimensions and 12 sub-dimensions (see figure 1). The primary dimensions are:

- *System quality:* the patient's perception of the website technology quality/characteristics enabling the telecommunication between the parties.
- *Interaction quality:* the patient's perceived quality of interaction with the doctor.
- *Use quality*: the patient's perceived efficient and informed usage of communication, service management and technology to achieve the desired outcome.

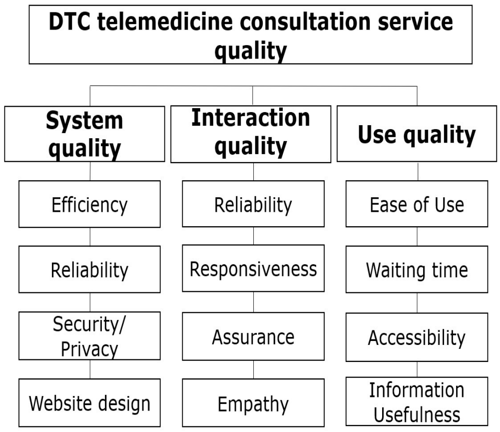


Figure 1 - Proposed conceptual service quality model for DTC telemedicine consultation (dimensions and subdimensions)

These dimensions consist of the following subdimensions (see table 1 for definitions):

- *efficiency, reliability, security/privacy and web design*
- *reliably, responsiveness, assurance and empathy*
- *ease of use, waiting time, accessibility, information usefulness*

Table 1: DTC telemedicine quality dimensions, subdimensions and definitions

Dimensions	Subdimensions	Definition		Adapted from:
System quality (Human-technology Interaction quality)	*Efficiency*	*The degree to which the DTC telemedicine platform is:*	easy to access and provide fast-loading, processing time to support information sharing (sound quality and image resolution).	(Santos, 2003); (Parasuraman, Zeithaml and Malhotra, 2005); (Lerouge, Garfield and Hevner, 2014)
	Reliability		dependable over time, functions as designed to perform the promised service accurately and consistently.	(Santos, 2003); (Akter, D'Ambra and Ray, 2010); (Lerouge, Garfield and Hevner, 2014)
	Security/Privacy		safe and protects the health information provided to and by the patients.	(Parasuraman, Zeithaml and Malhotra, 2005); (Akter, D'Ambra and Ray, 2013); (Wolfinbarger and Gilly, 2003)
	Website design		easy to use and aesthetic due to its clear layout and visually pleasing design.	(Loiacono, Watson and Goodhue, 2002); (Bauer, Falk and Hammerschmidt, 2006)
Interaction quality (Human-human Interaction quality)	*Reliability*	*The patient's perception of the doctor:*	delivering the promised service in an accurate and dependable manner.	(Parasuraman, Zeithaml and Berry, 1988); (Abuosi and Atinga, 2013); (Xing *et al.*, 2020); (Tripathi and Siddiqui, 2020)
	Responsiveness		being willing to assist and help him promptly.	
	Assurance		inspiring confidence by demonstrating courtesy, expertise and ability.	
	Empathy		focusing on his best interest and showing personal attention.	
Use quality	*Ease of use*	*The patient's perceived:*	ease of understanding and operating the technology and all website, consultation features.	(Loiacono, Watson and Goodhue, 2002); (Lerouge, Garfield and Hevner, 2014); (Zhang *et al.*, 2020)
	Waiting time		timeliness to connect to a doctor	(Che Rose *et al.*, 2004); (Dagger, Sweeney and Johnson, 2007); (Zineldin, 2006); (Lu *et al.*, 2020)
	Accessibility		ability to connect to a doctor at anytime	(Akter, D'Ambra and Ray, 2013); (Lu *et al.*, 2020); (Zhang *et al.*, 2020)
	Information Usefulness		quality of information received during and at the end of the remote consultation.	(Andaleeb, 2001); (Akter, D'Ambra and Ray, 2013); (Lerouge, Garfield and Hevner, 2014); (Zhang *et al.*, 2020)

METHODS

1. Orientation to the Delphi technique

Given the exploratory nature of the proposed conceptual model, the authors deemed necessary to conduct further empirical investigation to ensure the reliability and adequacy of the model and its dimensions. For this purpose, the Delphi technique was selected as it enables to gather insights, expert feedback on a specific issue or topic, in particular when information or empirical evidence is sparce or lacking (Beiderbeck *et al.*, 2021; Healy, Beccaria and McIlveen, 2021). It is a popular interactive group facilitation technique for forecasting, enhancing decision-making or solving complex problem by collecting the opinion of a panel of experts (Hasson, Keeney and McKenna, 2000; Landeta, 2006). Geographically scattered experts are systematically, repeatedly and individually questioned on the subject under discussion by means of a series of standardized questionnaires (often called rounds) with controlled opinion feedback (Ziglio, 1996; Hasson, Keeney and McKenna, 2000). During a Delphi study, the research team designs a first questionnaire which is sent to all participants. The questionnaires are completed anonymously (Hasson, Keeney and McKenna, 2000) and there is no direct interaction between experts to avoid negative group interaction effects (Landeta, 2006; Meijering and Tobi, 2016) (i.e. no fear of embarrassment (Linstone and Turoff, 1975), no influence of dominant personalities (Landeta, 2006)). Through a process of structured data-collection, the responses are then aggregated, summarized and converted into a second new questionnaire by the researchers. This second questionnaire that represents the results of the first round is fed back to the participants giving the experts the opportunity to revise their initial answers based on the position of the panel (Linstone and Turoff, 1975; Ziglio, 1996; Landeta, 2006). The series of rounds can continue as many times as necessary until no further consensus can be achieved (Ziglio, 1996; Hasson, Keeney and McKenna, 2000). However, the literature suggest two (Hasson, Keeney and McKenna, 2000) or three (Hasson, Keeney and McKenna, 2000; Hsu and Sandford, 2007) rounds are sufficient to collect the panel's opinions and generate consensus. As part of the Delphi process, the first round usually comprises an open-ended questionnaire to "*generate ideas and allow participants complete freedom in their responses*"(Hasson, Keeney and McKenna, 2000, p. 1011). In round two, participants review the results from round one and it is customary to ask experts to rank and/or rate the items obtained from the first questionnaire to define and hierarchize priorities (Ziglio, 1996; Hsu and Sandford, 2007). Alternatively, in round one a more structured questionnaire based on a review of the existing literature on the topic of interest can be designed by the research team (Hsu and Sandford, 2007). Here the experts are presented with a list of existing items or statements to rank and comment. The participants are also invited to suggest additional items. Round 2 comprises the collective rating of each item, the experts may revise their initial position or provide further comments. New suggested items derived from round one are also presented for consideration. At this stage, a deeper understanding of the subject of discussion is gained and it is possible to identify areas of agreement or disagreement among the panel (Ziglio, 1996; Hsu and Sandford, 2007). In round three, the participants are presented with the results, updated ratings and list of items that have achieved consensus (Hasson, Keeney and McKenna, 2000). Additional rounds can be conducted if important disagreement persist, certain issues need further clarification or to reach a collective opinion (Ziglio, 1996; Hsu and Sandford, 2007). The technique is therefore well suited for building consensus or attaining a certain degree of agreement on a specific topic (Hasson, Keeney and McKenna, 2000; Meijering and Tobi, 2016).

However, the Delphi technique is also criticized for its inconsistent approach in defining consensus and lack of unified methodological guideline to measure the level of agreement among experts (Boulkedid *et al.*, 2011; Diamond *et al.*, 2014; Giannarou and Zervas, 2014). As a result, a variety of descriptive statistics have been used by researchers to quantify and determine consensus: certain level of agreement in percentage, average percent of majority opinions Cut-off Rate, measures of central tendencies (mode, median and mean) or measures of dispersion (range, standard deviation, interquartile range and coefficient of variation) (von der Gracht, 2012)). There are research evidence to support the use of the median and interquartile over the mean and standard deviation as they are more robust and resistant to extreme outliers (Murphy *et al.*, 1998). While there is no agreement on the best approach, many studies use percent agreement (with same rating or proportion within a specific rating range) (von der Gracht, 2012; Diamond *et al.*, 2014)) or a combination of median score and percent agreement (Boulkedid *et al.*, 2011) to determine consensus. The level of agreement approach is especially relevant when Likert scales are used to determine consensus (von der Gracht, 2012). However, the level of agreement varies between studies. In 2007, Hsu reported that Ulschack (1983) recommended that consensus was achieved when 80% of the responses fell within two categories on a seven-point scale, whereas Green (1982) suggested the use of a median of 3.25 or higher and at least 70% of panel scoring three or four on a four-point Likert scale (Hsu and Sandford, 2007). Other authors, Scheibe et al. (1975), Dajani et Al. (1979), also challenged the reliability and adequacy of the percent agreement approach and proposed as an alternative to measure the group stability of responses between rounds (Hsu and Sandford, 2007; von der Gracht, 2012). The measure of consensus varying from study to study, several authors conducted systematic reviews on how consensus has been measured in articles that used the Delphi method. Gracht et al. (2012) concluded that "*the measurement of consensus alone is not sufficient for Delphi studies*"(von der Gracht, 2012, pp. 1532–1533), the stability and convergence of responses between round should also be tested via the use of inferential statistics (e.g., Chi square test for independence, Kendall's W coefficient of concordance, Wilcoxon matched-pairs signed-ranks test). To remedy the criticism on the lack of empirical rigor of the Delphi method, (Boulkedid *et al.*, 2011) and (Diamond *et al.*, 2014) highlighted the importance for Delphi investigators to clearly specify the methods used to plan, administer and report the results of their studies. Both authors published practical guidelines with key quality indicators, methodologic criteria to include in future Delphi studies, for instance: the objective of the study, selection and exclusion criteria for the participants, definition of consensus and criteria to include or eliminate an item, presentation methods of the qualitative and quantitative results, etc.

2. *Study design*

Aim

The aim of the study is to refine and validate the conceptual model developed by the authors by establishing consensus on the service dimensions to measure service quality of DTC telemedicine consultation.

Experts' selection

There is no consensus on "*the optimal of subjects in a Delphi study*"(Hsu and Sandford, 2007, p. 3). The experts panel construction is not dictated by specific rules and will depend on the purpose of the study. Researchers must seek what size and panel composition will be the more meaningful for the subject under discussion (Ziglio, 1996; Akins, Tolson and Cole, 2005). The literature suggests when the panel's background is homogenous, good results can be obtained with small groups of 10 to 15 experts (Ziglio, 1996; Hsu and Sandford, 2007). In Delphi studies, experts are commonly defined as individuals who have expertise, knowledge and experience with the topic being investigated (Ziglio, 1996; Keeney, Hasson and McKenna, 2006; Hsu and Sandford, 2007) and who are also willing and capable to participate and contribute to the survey (Ziglio, 1996; Hasson, Keeney and McKenna, 2000). Taking into account the aim of this Delphi study is to identify and validate service dimensions for measuring service quality of DTC telemedicine consultation from a patient perspective, the authors opted for a heterogenous panel composed of 10 patients, 10 teleconsultants and 3 service quality academics (Upadhyai et al., 2021). In the context of the study, both the opinions of the medical practitioners providing care and the patients receiving care are considered pertinent as their understanding of service quality may differ (Ziglio, 1996).

Purposive sampling will be used to ensure the invited participants met the inclusion criteria and to obtain wide geographical coverage. All participants are required to (1) be fluent English readers and (2) be aged over 18 years old. Patients are required to have had at least one teleconsultation in the previous twelve months and teleconsultants to have at least one year of experience as a telemedicine physician (general practitioner or specialist).

Consensus definition and number of rounds

No predetermined number of rounds is stipulated; however, it is anticipated consensus would be reached in 3 rounds (Hasson, Keeney and McKenna, 2000; Hsu and Sandford, 2007). Experts will be invited to take part in a Delphi survey of a minimum of 3 rounds and a maximum of 4. A minimum of 3 rounds is needed to consult the experts twice on the same items (Landeta, 2006) and give them the opportunity to revise their initial answer, given the panel will be invited during Round 1 to suggest additional items that may be lacking from the conceptual framework.

Consensus criteria for the inclusion or exclusion of an item were evaluated and defined a priori (Boulkedid *et al.*, 2011; Diamond *et al.*, 2014) by the research team based on a combination of descriptive and inferential statistics (von der Gracht, 2012). In line with other studies, consensus was considered to be reached when an inter-quartile score of less than 1.0 (von der Gracht, 2012; Mao, Loke and Hu, 2020) is obtained and at least 70% of the participants agree/strongly agree (Slade *et al.*, 2016; Vogel *et al.*, 2019) that an item should be included on a 5-point Likert scale (1= strongly disagree; 2= disagree; 3=

partially agree; 4= agree; 5= strongly agree). The content validity will be calculated per item and any I-CVI of 0.78 or higher would be considered as statistically significant (Polit, Beck and Owen, 2007; Mao, Loke and Hu, 2020). For this purpose, the participants will be invited to rate the relevance of each item of the conceptual model on a 5-point Likert scale (with 1 = absolutely irrelevant, 2 = not relevant, 3=neutral, 4=relevant, 5 = highly relevant) (Mao, Loke and Hu, 2020; Upadhyai et al., 2021). Ratings of 1 or 2 are combined as *not relevant* and ratings of 4 or 5 as *relevant* (Zamanzadeh et al., 2015; Upadhyai et al., 2021).

Thus, items that reaches the pre-established cut-off (inter-quartile score of less than 1.0, minimum of >70% of participants with a level of agreement ≥ 4 and a I-CVI of 0.78 or above) after 2 rounds are included in the final framework. To ensure the stability of responses, both the multi-rater kappa coefficient for the degree of agreement beyond chance and the Kendall coefficient W test (von der Gracht, 2012) (with significant agreement set at ($p<0.05$) (Mao, Loke and Hu, 2020; Funabashi *et al.*, 2021)) will be adopted. The overall scale validity (S-CVI) will be tested and excellent content validity set at a S-CVI/UA of 0.80 or higher and a S-CVI /Ave of 0.90 or higher (Polit, Beck and Owen, 2007; Mao, Loke and Hu, 2020).

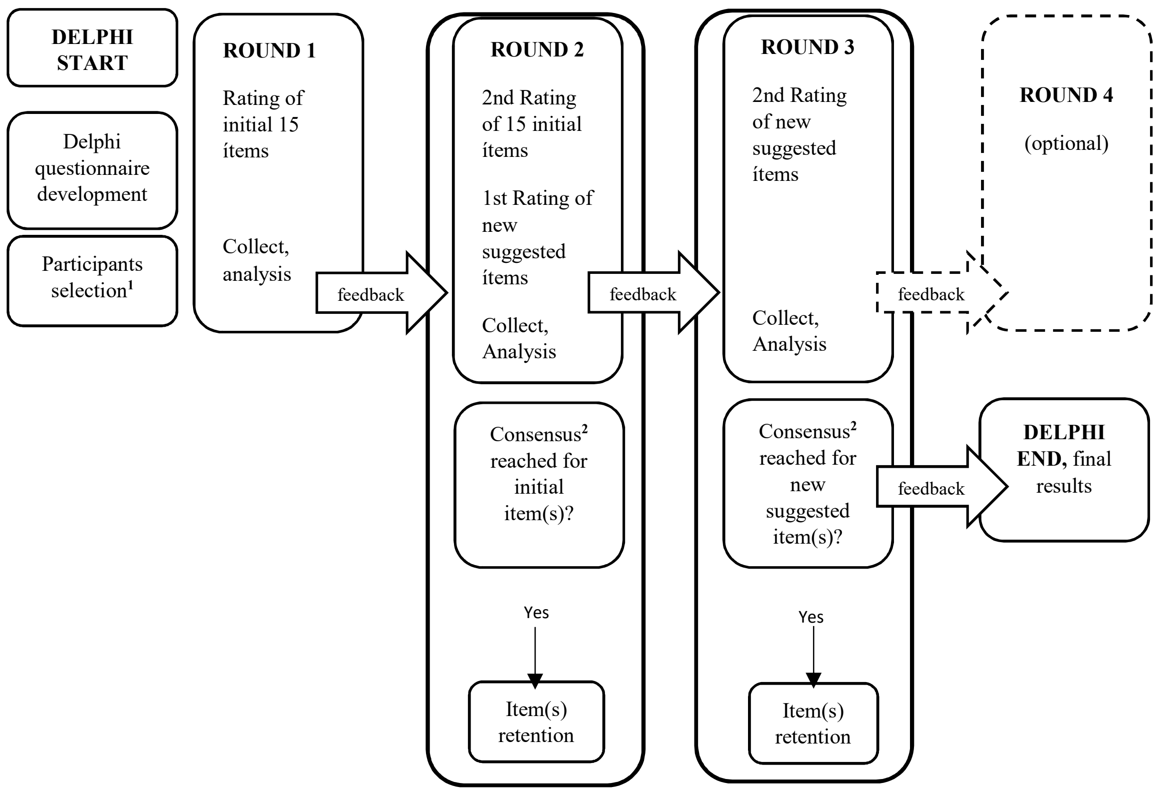
Delphi procedure

An online survey software was used to develop the first questionnaire and three rounds are anticipated to reach consensus (see figure 2 for the process of Delphi rounds).

In **Round 1**, the participants will receive along with the first questionnaire, an introduction letter outlining the research question, aim of the study and presentation of the conceptual service quality model and its components (dimensions, subdimensions and their definitions). For each dimension (3) and subdimension (12) identified by the authors, the panel will be invited to rate their level of agreement on a 5-point Likert scale (with 1 being the lowest level and 5 the highest) that the item significantly and positively impacts patients perceived service quality of telemedicine consultations. Panelists will be encouraged to justify their ratings, comment on the underlying reasons for their responses and suggest any wording simplification and or clarification. In parallel, the panel will be asked to rate the degree of relevance of each item for the measurement of the domain it intends to measure. During the first round, the participants will also be presented with open-ended questions and asked "*Is there a component of service quality that you believe has been missed in this model?*", "*Is there any way that you would suggest simplifying the existing model or any of its components*?". All qualitative data will be used to revise definitions, tailor the model, summarized and presented to the panel in the next round.

In **Round 2**, the results of the first round will be fed back to the participants for review (median, lowest, highest ratings and summary of the qualitative comments). All 15 initial items will be re-presented to the panel for a second rating. Dimensions and subdimensions that reach consensus (inter-quartile score of less than 1.0, minimum of >70% of participants with a level of agreement ≥ 4 and a I-CVI of 0.78 or above after 2 rounds) will be retained as part of the final model. The new suggested dimensions will be presented to the panel for rating and review. Similarly, the new items that reach consensus in **Round 3** will be retained.

A final round (**round 4**) will be held if certain issues need further clarification or to give participants a last opportunity to revise their responses.



[1] 10 patients, 10 teleconsultants and 3 academics

[2] inter-quartile score of less than 1.0, minimum of >70% of participants with a level of agreement ≥ 4 and a I-CVI of 0.78 or above after 2 rounds

Source: Adapted from (Henderson and Rubin, 2012)

Figure 2 - Flowchart of the planned Delphi study

CONCLUSION

The present article outlines the protocol that will be used to verify the validity of the conceptual service quality model for Direct-to-Consumer (DTC) telemedicine consultation. The Delphi technique was selected as it is a popular interactive group facilitation technique for gathering expert feedback on a specific issue, in particular when empirical evidence is lacking. While the technique is well suited for building consensus, the lack of unified consensus definition and methodology to plan and administer the survey have raised concerns. In order to overcome this problem, the authors have carefully designed the study and will rely on published practical Delphi guidelines to produce relevant results. This first consists of a clear indication of the study objective: the refinement and validation of the conceptual model by establishing consensus on the service dimensions to measure service quality of DTC telemedicine consultation. Then, a panel composition that is meaningful for the study with explicit selection criteria for participants: 10 patients who had at least one teleconsultation in the previous twelve months, 10 teleconsultants with at least one year of experience and 3 service quality academics. Finally, a clear definition of consensus and criteria to include an item, defined a priori and based on a combination of descriptive and inferential statistics: inter-quartile score of less than 1.0, minimum of >70% of participants with a level of agreement ≥ 4 and a I-CVI of 0.78 or above after 2 rounds. At this stage, the first round of the Delphi study has not been completed. The authors have developed the first questionnaire and are finalizing the participants' selection and recruitment.

REFERENCES

Abuosi, A.A. and Atinga, R.A. (2013) 'Service quality in healthcare institutions: establishing the gaps for policy action', *International journal of health care quality assurance*, 26(5), pp. 481–492. doi:10.1108/IJHCQA-12-2011-0077.

Akins, R.B., Tolson, H. and Cole, B.R. (2005) 'Stability of response characteristics of a Delphi panel: Application of bootstrap data expansion', *BMC Medical Research Methodology*. doi:10.1186/1471-2288-5-37.

Akter, S., D'Ambra, J. and Ray, P. (2010) 'User perceived service quality of mHealth services in developing countries'.

Akter, S., D'Ambra, J. and Ray, P. (2013) 'Development and validation of an instrument to measure user perceived service quality of mHealth', *Information and Management*, 50(4). doi:10.1016/j.im.2013.03.001.

Andaleeb, S.S. (2001) 'Service quality perceptions and patient satisfaction: A study of hospitals in a developing country', *Social Science and Medicine*, 52(9). doi:10.1016/S0277-9536(00)00235-5.

Bauer, H.H., Falk, T. and Hammerschmidt, M. (2006) 'eTransQual: A transaction process-based approach for capturing service quality in online shopping', *Journal of Business Research*, 59(7). doi:10.1016/j.jbusres.2006.01.021.

Beiderbeck, D. *et al.* (2021) 'Preparing, conducting, and analyzing Delphi surveys: Cross-disciplinary practices, new directions, and advancements', *MethodsX*, 8. doi:10.1016/j.mex.2021.101401.

Boulkedid, R. *et al.* (2011) 'Using and reporting the Delphi method for selecting healthcare quality indicators: A systematic review', *PLoS ONE*, 6(6). doi:10.1371/journal.pone.0020476.

Carman, J.M. (1990) 'Consumer perceptions of service quality: an assessment of the SERVQUAL dimensions', *Journal of Retailing VO - 66* [Preprint], (1).

Che Rose, R. *et al.* (2004) 'Hospital service quality: a managerial challenge', *International Journal of Health Care Quality Assurance*, 17(2/3), pp. 146–159. doi:10.1108/09526860410532784.

Dagger, T.S., Sweeney, J.C. and Johnson, L.W. (2007) 'A Hierarchical Model of Health Service Quality: Scale Development and Investigation of an Integrated Model', *Journal of Service Research*, 10(2), pp. 123–142. Available at: http://sire.ub.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eoah&AN=47862867&lang=es&site=ehost-live&scope=site.

Diamond, I.R. *et al.* (2014) 'Defining consensus: A systematic review recommends methodologic criteria for reporting of Delphi studies', *Journal of Clinical Epidemiology*, 67(4). doi:10.1016/j.jclinepi.2013.12.002.

Funabashi, M. *et al.* (2021) 'Expert consensus on a standardised definition and severity classification for adverse events associated with spinal and peripheral joint manipulation and mobilisation: Protocol for an international e-Delphi study', *BMJ*

Open, 11(11). doi:10.1136/bmjopen-2021-050219.

Giannarou, L. and Zervas, E. (2014) ‘Using Delphi technique to build consensus in practice’, *International Journal of Business Science and Applied Management*, 9(2).

von der Gracht, H.A. (2012) ‘Consensus measurement in Delphi studies. Review and implications for future quality assurance’, *Technological Forecasting and Social Change*, 79(8). doi:10.1016/j.techfore.2012.04.013.

Hasson, F., Keeney, S. and McKenna, H. (2000) ‘Research guidelines for the Delphi survey technique’, *Journal of Advanced Nursing*, 32(4). doi:10.1046/j.1365-2648.2000.t01-1-01567.x.

Healy, L.J., Beccaria, G. and McIlveen, P. (2021) ‘Revised model for evaluating visiting health care services in rural and remote settings’, *Australian Journal of Rural Health*, 29(5). doi:10.1111/ajr.12774.

Henderson, E.J. and Rubin, G.P. (2012) ‘Development of a community-based model for respiratory care services’, *BMC Health Services Research*, 12(1). doi:10.1186/1472-6963-12-193.

Hsu, C.C. and Sandford, B.A. (2007) ‘The Delphi technique: Making sense of consensus’, *Practical Assessment, Research and Evaluation*, 12(10).

Keeney, S., Hasson, F. and McKenna, H. (2006) ‘Consulting the oracle: Ten lessons from using the Delphi technique in nursing research’, *Journal of Advanced Nursing*, 53(2). doi:10.1111/j.1365-2648.2006.03716.x.

Ladhari, R. (2008) ‘Alternative measures of service quality: a review’, *Managing Service Quality: An International Journal*, 18(1), pp. 65–86. doi:10.1108/09604520810842849.

Ladhari, R. (2009) ‘A review of twenty years of SERVQUAL research’, *International Journal of Quality and Service Sciences*. doi:10.1108/17566690910971445.

Landeta, J. (2006) ‘Current validity of the Delphi method in social sciences’, *Technological Forecasting and Social Change*, 73(5). doi:10.1016/j.techfore.2005.09.002.

Lerouge, C.M., Garfield, M.J. and Hevner, A.R. (2014) ‘Patient perspectives of telemedicine quality’, *Patient Preference and Adherence*, 9. doi:10.2147/PPA.S67506.

Linstone, H.A. and Turoff, M. (1975) *The delphi method*. Addison-Wesley Reading, MA.

Loiacono, E.T., Watson, R.T. and Goodhue, D.L. (2002) 'WebQual: A measure of website quality', *American Marketing Association. Conference Proceedings*, 13.

Lu, W. *et al.* (2020) 'Research on Teleconsultation service quality based on multi-granularity linguistic information: The perspective of regional doctors', *BMC Medical Informatics and Decision Making*, 20(1). doi:10.1186/s12911-020-01155-5.

Mao, X., Loke, A.Y. and Hu, X. (2020) 'Developing a tool for measuring the disaster resilience of healthcare rescuers: A modified Delphi study', *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, 28(1). doi:10.1186/s13049-020-0700-9.

Meijering, J. V. and Tobi, H. (2016) 'The effect of controlled opinion feedback on Delphi features: Mixed messages from a real-world Delphi experiment', *Technological Forecasting and Social Change*, 103. doi:10.1016/j.techfore.2015.11.008.

Murphy *et al.* (1998) 'Consensus development methods, and their use in clinical guideline development.', *Health Technology Assessment*, 2(3). doi:10.3310/hta2030.

Parasuraman, A., Zeithaml, V.A. and Berry, L.L. (1988) 'Servqual a multiple-item scale for measuring consumer perception of service quality, Journal of Retailing', *Servqual a multiple-item scale for measuring consumer perception of service quality, Journal of Retailing*, 64(1).

Parasuraman, A., Zeithaml, V.A. and Malhotra, A. (2005) 'E-S-QUAL a multiple-item scale for assessing electronic service quality', *Journal of Service Research*, 7(3). doi:10.1177/1094670504271156.

Philip, G. and Hazlett, S.A. (1997) 'The measurement of service quality: A new P-C-P attributes model', *International Journal of Quality and Reliability Management*, 14(3). doi:10.1108/02656719710165482.

Polit, D.F., Beck, C.T. and Owen, S. V. (2007) 'Focus on research methods: Is the CVI an acceptable indicator of content validity? Appraisal and recommendations', *Research in Nursing and Health*, 30(4). doi:10.1002/nur.20199.

Santos, J. (2003) 'E-service quality: A model of virtual service quality dimensions', *Managing Service Quality: An International Journal*, 13(3).

doi:10.1108/09604520310476490.

Slade, S.C. *et al.* (2016) 'Consensus on exercise reporting template (Cert): Modified delphi study', *Physical Therapy*, 96(10). doi:10.2522/ptj.20150668.

Tripathi, S.N. and Siddiqui, M.H. (2020) 'Assessing the quality of healthcare services: A SERVQUAL approach', *International Journal of Healthcare Management*, 13(S1). doi:10.1080/20479700.2018.1469212.

Upadhyai, R. *et al.* (2021) 'Development and validation of a scale for measuring hospital service quality: a dyadic approach', *Journal of Health Research* [Preprint]. doi:10.1108/JHR-08-2020-0329.

Vogel, C. *et al.* (2019) 'A Delphi study to build consensus on the definition and use of big data in obesity research', *International Journal of Obesity*, 43(12). doi:10.1038/s41366-018-0313-9.

Wolfinbarger, M. and Gilly, M.C. (2003) 'eTailQ: Dimensionalizing, measuring and predicting etail quality', *Journal of Retailing*, 79(3). doi:10.1016/S0022-4359(03)00034-4.

Xing, W. *et al.* (2020) 'How does online doctor–patient interaction affect online consultation and offline medical treatment?', *Industrial Management and Data Systems*, 120(1). doi:10.1108/IMDS-05-2019-0261.

Zamanzadeh, V. *et al.* (2015) 'Design and Implementation Content Validity Study: Development of an instrument for measuring Patient-Centered Communication', *Journal of Caring Sciences*, 4(2). doi:10.15171/jcs.2015.017.

Zhang, M. *et al.* (2020) 'Measuring hospital process service quality: emerging technologies' challenge', *International Journal of Quality and Service Sciences*, 12(3), pp. 319–336. Available at: http://sire.ub.edu/login?url=https://search.ebscohost.com/login.aspx?direct=true&db=eoah&AN=54739691⟨=es&site=ehost-live&scope=site.

Ziglio, E. (1996) 'The Delphi Method and its Contribution to Decision-making', in *Gazing Into the Oracle: The Delphi Method and Its Application to Social Policy and Public Health*.

Zineldin, M. (2006) 'The quality of health care and patient satisfaction: An exploratory investigation of the 5Qs model at some Egyptian and Jordanian medical clinics',

International Journal of Health Care Quality Assurance.
doi:10.1108/09526860610642609.

Quality 4.0 Concept and its Implementation in Saudi Organizations

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ABSTRACT

Purpose – The quality of disruption or Quality 4.0 is not an exclusive concept. However, there is a lack of literature related to quality 4.0 concept and definition. The purpose of this paper is to understand and deeply demonstrate the concept and definition of Quality 4.0 and its possible implementation within Saudi context.

Design/methodology/approach - For this paper, an exploratory bibliographic research was conducted in order to extract the most important ideas from the literature.

Findings – This paper shows that Quality 4.0 is laying on three pillars namely: People, Process, and Technology and been nourished by three factors which are: Connectedness, Intelligence, and Automation. Moreover, there was slightly adoption and intends for implementation in some Saudi organizations and the Saudi National Vision Programs in particular.

Research limitations/implications- The literature review was limited to a database and can be expanded or other database can be included.

Originality/value – This paper fills a research gap and contributes to a better perception by providing a concept and definition of Quality 4.0 and its implementation in Saudi context.

Keywords: Quality 4.0, Implementation, Saudi organizations, Digital transformation.

Paper type: Literature review

INTRODUTION AND BACKGROUND

Today, we are living in a world driven by a new digital shift that is destabilizing and disrupting recognized business models and standards. This requires businesses and government organizations to change the classical way of thinking, our methods to manage manufacturing and production processes, and the whole product life cycle and value creation (Zairi, 2017).

Thus, with regard to the steady increase in the revolution in the world of communication technology, the Internet of things, smart and intelligent devices, which is driving towards the emergence of smart manufacturing systems. The latter influenced modern industries and affected the efficiency of work nature of these factories and higher performance of the supply chain, and contributed to the production of a product with creative characteristics basically based on customers` desires and aspirations. This leads to the emergence of a new term called “Quality 4.0” which stems from the Fourth Industrial Revolution (Industry 4.0) that originally appeared as a term during the Hannover Fair 2011 in Germany. Leaders in all sectors need to accept and adopt the idea of disruptive change driven by the digital transformation and to deal with this transformation with a clear and specific strategy to truly serve the National strategies for sustainable development.

The Kingdom of Saudi Arabia leadership launched its ambitious Vision 2030, which aims to achieve a leading position for the Kingdom in the global economy. The vision is articulated on a set of strategic directions aimed at diversifying economic sectors, localizing strategic industries, and investing in promising sectors such as mining, renewable energy and military industries. The vision also aims to build and develop national capabilities, create job opportunities for Saudi youth, and maximize productive industrial assets, thus enabling the Saudi economy to enhance its competitive capabilities. The National Industrial Development and Logistics Program (NIDLP) was launched as one of the vision realization programs, with the aim of transforming the Kingdom of Saudi Arabia into a leading industrial power and a global logistics centre in promoting the growth of its manufacturing sectors with a strong focus and benefit from the technologies of the Fourth Industrial Revolution (Industry 4.0).

The Saudi manufacturing companies are required to operate in a completely new technological environment and should build their capabilities to compete at the local and global scales. In order to overcome these challenges, industrial sector organizations will need new capabilities to manage the value chain in their products in a flexible and lean way. Industry 4.0 is one of the essential components of the national program (NIDLP) that drives the economic development and the manufacturing sector. It is indeed a key enabler for achieving and sustaining the competitive advantage of national companies in a highly competitive global market, sought within the Saudi Vision 2030. Within this national economic and industrial momentum, Quality is considered as a major component of all the strategic programs that articulate the Vision (NIDLP, 2020).

Though the vision 2030 and its supporting strategic programs were officially launched in 2016, little research was devoted to the concepts of "Industry 4.0", its impact on the "quality management implementation", and the newly developed concept of "Quality 4.0" within the Saudi industrial context. The objective of the present paper is to make a review of the available literature concerning the management of Quality within the perspective of Industry 4.0 context, with a specific focus on its implementation in Saudi industrial organizations. The paper fills this research gap and contributes to a better perception of the concept of "Quality 4.0" and its implementation in the Saudi context.

METHODOLOGY

This study is based on a bibliographic review, initially made through the reading of books related to the subject and then through a search and selection of articles in the Google Scholar Academic database, focused on Quality 4.0 Concept and its Implementation. The keywords used during the search of the articles were: Quality 4.0, Concept, Implementation, Saudi organizations, Digital transformation. The criterion used in the selection of articles was the choice of those articles that directly addressed the concept of Quality 4.0 and where this was the central theme of the present paper.

The schematic representation of the research methodology adopted in the present paper is shown in figure (1).

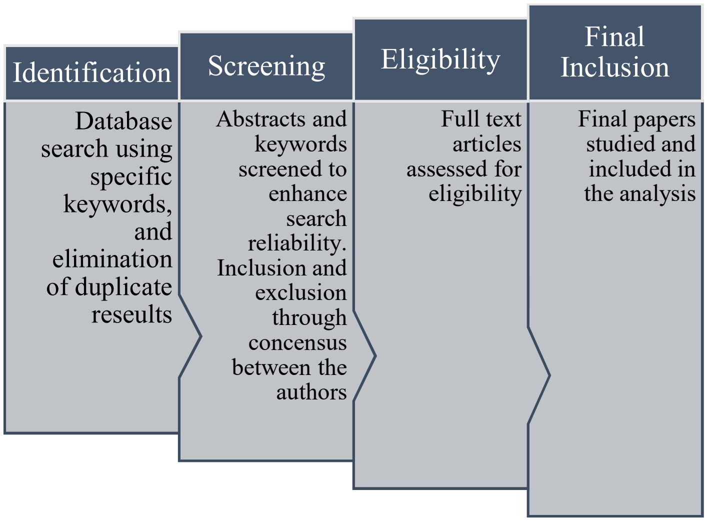

Figure 1 - Litterature review Approach Flowchart (Adapted from Palmatier et al., 2018)

The approach presented in figure (1) is based on "carefully identify and synthesize relevant literature in order to evaluate a specific research domain and build a conceptual model for a better understanding of the research issue (Palmatier et al., 2018).

REVIEW OF THE LITERATURE AND DISCUSSION

Industry 4.0 concept

As a phased extension of industry development which started at the end of the 18th century to the beginning of the 19th as the First Industrial Revolution with the introduction of mechanical production lines. Then, the Second Industrial Revolution started at the end of the 19th century, with massive technological advancements in the field of industries that helped the emergence of a new source of energy such as: electricity, gas, and oil. In the second half of the 20th century, the world witnessed the Third Industrial Revolution which brought the Automation of production by electronics and IT. The Third Revolution is still present, but it is transforming into a new age of industrialization – the Fourth Industrial Revolution (Industry 4.0) that is smoothly taking over (Figure 2).

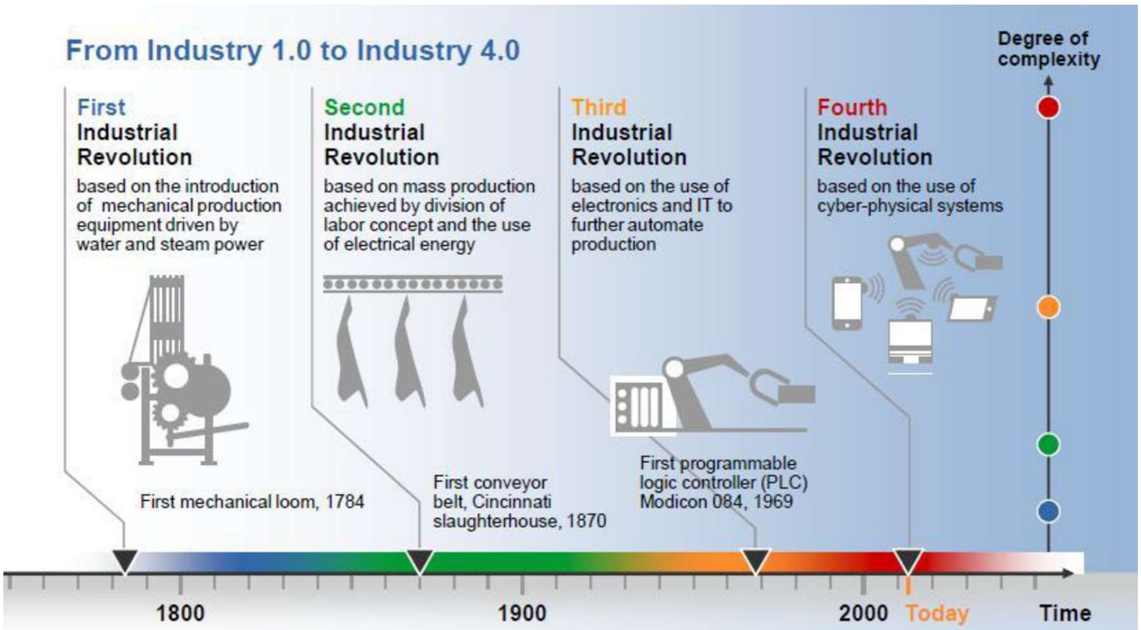

Figure 2 – The four industrial revolutions (Zairi, 2019).

There is still a debate about the term of "Revolution and Evolution", where some people prefer the term of evolution as the transformation will take several decades and the main elements, which constitute this transformation process, are already exist and will be only developed further. On the other hand, the term "revolution" is validated, as the transformation has similar characteristics to an epochal transformation due to a paradigm shift in manufacturing (Zonnenshain & Kenett, 2020). One agreed definition is that it will be an (r)evolution towards digitalization.

The term Industry 4.0 was made by the Communication Promoters Group of the Industry-Science Research Alliance in 2011. It defines Industry 4.0 as "[…] the fourth industrial revolution, a new level of organization and control of whole value chains over the entire lifecycle of products. This cycle includes the fulfilment of individualized customer requirements and extents itself from idea, real order, development, and manufacturing, delivery to the customer and the recycling process with the involved services. The basis for the development is formed by the availability of all necessary information in real-time through interconnection of all instances, which are involved in value creation as well as through the ability to derive the best possible value stream based on the resulting data. Through the connection of people, objects, and systems, dynamic, real-time optimized, self -organizing, cross-company value networks will evolve, which can be optimized based on different criteria such as costs, availability and resource efficiency."(Bartodziej, 2017). In 2013, the National Academy of Science and Engineering (Acatech) perceived

Industry 4.0 as "[…] the technical integration of Cyber Physical Systems (CPS) into manufacturing and logistics and the use of the Internet of Things and Services in industrial processes. This will have implications for value creation, business models, downstream services and work organization."(Bartodziej, 2017).

Quality

Quality is a subjective concept that is strongly tied to each individual's views. There is no specific definition of quality. Culture, kind of product or service, requirements, and expectations are just a lot of small aspects that have a direct impact on the definition of quality. Because quality has so many different meanings, it's not always obvious and objective (Pinto and Romero, 2020).

Quality is a concept that is difficult to describe but easy to identify when it refers to something that is good or outstanding. In this regard, a product's and/or service's quality is linked to its characteristics, which may or may not meet an individual's requirements (Gaster et al., 2003).

Table 1 Illustrates some examples of quality definitions.

Table 1 – Some quality definitions

Author	Year of Publication	Definition
Walter A. Shewhart	1920	There are two common aspects in quality. One is the person who clings to the real and objective quality of something, regardless of the existence of men. The other is linked to what we think, feel or experience as a result of this objective reality.
W. Edwards Deming	1982	The ability to satisfy desires.
Joseph M. Juran	1954	Suitability for the use.
Kaoru Ishikawa	1973	The ability to develop, design and produce (...) in the most economical, useful and pleasant way for the customer.
Armand V. Feigenbaum	1954	The best for some customer requirements, being these requirements: utility and selling price of the product.
Geinichi Taguchi	1980	The damage caused to society by the product, from the moment it is sold to the customer.

Philip B. Crosby	1986	Compliance with requirements. Zero defects.
Paulo Sampaio	2014	Give to the customers what they want and try to overcome their expectations.
Mohamed Zairi	2017	Quality is the answer to all our needs. It protects our life, nourishes our senses, guides our dreams and defines our purpose.

Source: adapted from Pinto and Sampaio (2020)

According to the standard ISO 9000: 2015, quality is defined as "the degree of satisfaction of requirements given by a set of intrinsic characteristics of an object," and the success of any organization is directly dependent on its ability to mobilize and organize the means and resources required to deliver products and/or services that meet the requirements, needs, and expectations of its customers(*ISO 9000:2015(En), Quality Management Systems — Fundamentals and Vocabulary*, n.d.). As a result, quality is the "engine" of each organization's success, as well as its recognition, competitiveness factor, and product/service selection. The construction of a culture based on quality principles and values will pave the way for the effectiveness and continuous improvement of procedures and processes (Pinto and Romero, 2020).

The strong competition among organizations, reinforced by the challenge of expanding economic globalization, relaunches and emphasizes the importance of meeting consumers' needs. Quality is therefore becoming an increasing imposition, regardless of the market in which the organization operates, and is frequently seen as a criterion for selection or exclusion. Quality of products and/or services, on the other hand, are not the result of inspiration or chance: the organization must demonstrate that it has the means and resources necessary for the development of quality products and/or services, as well as their continuous improvement, in order to keep up with the growing and natural increase in customer demand.

Quality has become a non-negotiable criterion for enterprises, since the implications of putting a "non-compliant" product or service on the market may be disastrous and threaten the organization's future sustainability. Organizations must constantly improve their products, practices, and personnel due to the extremely competitive market. Many Japanese companies have adopted "Kaizen," a philosophy of personal, organizational, and social development that has made significant contributions to the advancement of quality concepts by spreading Deming's principles, such as the well-known Plan-do-check-act (PDCA) Cycle. Various Japanese administrative production practices, such as Total Quality Control, Zero Defect, and Just in Time, were preserved by Kaizen (Pinto and Sampaio, 2020).

Quality 4.0

Quality is embedded in the industrial revolutions and accordingly has evolved in many aspects such as: (1) Product Quality, (2) Process Quality, (3) Service Quality, (4) Management Quality, (5) Design Quality and (6) Information Quality (Zonnenshain A. and Kenett R.,2020). Sisodia and Forero (2020) developed the meaning of quality into 4 phases of quality: in the phase of (Quality Control), the meaning of quality is inspection, and its meaning is design in the (Quality Assurance) phase, and the meaning of quality is empowerment in the phase of (Total Quality Management), and in the last phase of (Quality 4.0), the quality meaning is innovation. Quality 4.0 is a term that references the future of quality within the context of Industry 4.0. It is for everyone, any business system that has hierarchies or networks, where data can be collected at any level, can benefit from the new technologies that support connectedness. Moreover, It enhances connectedness, intelligence, and automation so that employees, devices, and data may collaborate to improve performance and meet corporate goals (Radziwill, 2020).

Zairi (2017) suggested such a response to the crisis of the quality profession. He proposed that the quality profession needs a new quality DNA by changing the way of understanding of quality as a concept and the notion of customer satisfaction. While technology and the external environment will change in the future decades, the quality professional's responsibility will stay the same: to align people, processes, and technologies to help enterprises meet their aims and provide organizational outcomes in a sustainable basis (Radziwill, 2020). Quality 4.0 represents an opportunity to utilize Industry 4.0 technologies to realign quality functions with broader organizational strategy.

Quality 4.0 is still in lack to be defined because of the lack of concept awareness by the organizations. Sisodia and Forero (2020) proposed the following definition for Quality 4.0: “Quality 4.0 refers to the digitalization of Total Quality Management and its impact on quality technology, processes and people. It builds upon traditional quality tools and considers also connectedness, intelligence and automation for improving performance and making timely data-driven decisions in an end to end scenario, involving all the stakeholders and providing visibility and transparency”.

The Charted Quality Institute (CQI) embarked on a significant three-month research project to clearly define Quality 4.0 as "Quality 4.0 is the leveraging of technology with people to improve the quality of an organisation, its products, its services and the outcomes it creates.". In this context, it is worthwhile to consider the proposed new definition of Quality 4.0 by Dias et al. (2021) which is " Quality 4.0 is thus the delivery of superior quality, using modern technology to augment the capabilities of both people and quality tools and methods.".

Zairi (2019), argued that Quality 4.0 blends the new digital technologies with traditional quality methods to arrive at new optimums in Operational Excellence, performance, and innovation. These new technologies include Machine Learning, Artificial Intelligence, connected devices and operations, new forms of collaboration like social media and blockchain, Big Data, Cloudcomputing, and new apps like AR/VR and mashups (Zairi, 2019). Six principles were proposed to govern the concept of Quality 4.0, and to form any model of implementation in organizations; These include the principles shown in Figure 3, which are:

- Making quality the licence to manage the organization;
- Redefining quality to ensure the organization remains relavant;
- Ensuring that quality orientation is the driver of organizational excellence
- Developing transformational and disruptive capability;
- Building excellence maturity through transformation-based performance impact;
- Sustaining the path of excellence by shaping the future through disruptive quality behavior.

Figure 3 – The Six Principles of Quality 4.0 (Zairi, 2019)

Quality 4.0 in Saudi Context

Saudi Arabia, a Group of Twenty (G20) member, as many developing countries, seeks to develop its production and service sectors thorough the adoption of the 2030 strategic vision and ambitious programs. Such as: National Industrial Development and Logistics Program (NIDLP) which has a target to develop the industrial sector to deliver high quality products through the adoption of Industry 4.0 technologies. The program, which falls within the Vision 2030 realization programs is mainly articulated on four strategic pillars, shown in Figure (4). The first pillar considers accelerating innovation to maintain current features and formulate new ones based on Industry 4.0 technologies.

The second pillar consists of supporting technological innovation and industry 4.0 application to improve both productivity and quality of various industrial investments (Military industries, Food industries, Medical devices etc …). Industry 4.0 is a key component to generate an economic impact on the Kingdom`s industries through high quality products by 2030 (NIDLP, 2020). This is targeted to lead to the adoption of connected, intelligent, and automated systems which will subsequently lead to a renaissance in quality management methodologies, techniques and tools defined as "Quality 4.0".

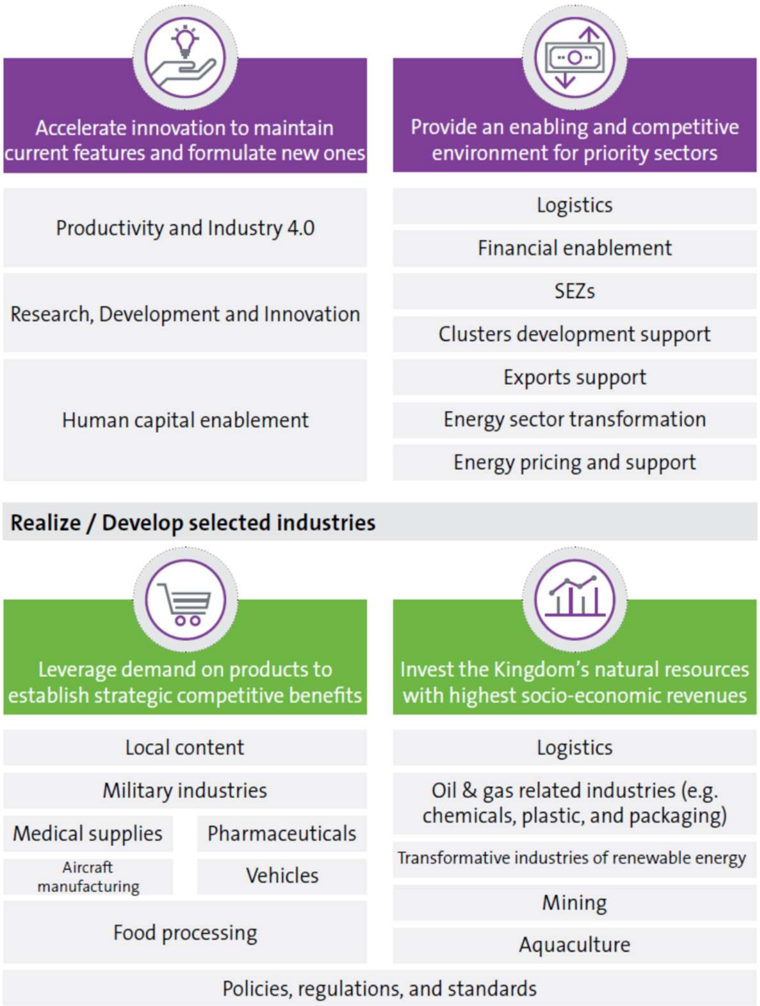

Figure 4 - The NIDLP main Pillars and Components (NIDLP, 2020)

Though the importance of the concept of "Quality 4.0" for the Saudi context, the authors argue that little research has been devoted to this topic and there is a clear research gap in investigating this important research issue.

A PROPOSED MODEL FOR QUALITY 4.0 IMPLEMENTATION

Since Quality 4.0 is still in its infancy stage and a new phenomenon, there is still a need for contemporary definitions, adequate case studies and frameworks (Dias et al., 2021). In this respect, most of studies which were reviewed in the present paper have tackled Quality 4.0 from several angles namely: people, processes, data (technology), connectedness, intelligence and automation. The analysis of the previous definitions of the concept of "Quality 4.0" led the researchers to make a proposal for a conceptual model for Quality 4.0 as shown in Figure (5).

Figure 5 – Quality 4.0 Model

The new developed model for Quality 4.0 considers people, process and technology at the foundation of the model as three pillars to maintain and prepare for Quality 4.0 implementation. The component related to "People" is strongly linked to one of the Vision Realization Programs which is "Program for Human Capital Development". By "Technology" it is meant by all the technologies embedded in Industry 4.0. The "Process" component deals with all the manufacturing and management processes needed to operate industrial processes and logistics services. The three pillars are considered as the infrastructure of Quality 4.0 and they are recognized as mandatory to be existed in the organizations. The three factors on the top of the model are vital factors to nourish the foundation pillars and drive the turbine wheel to make sure the manifestation of Quality 4.0. It is believed that the proposed conceptual model needs further discussion and studies for validating within real industrial settings.

CONCLUSIONS

The present paper reviewed the relevant literature on the concept of "Quality 4.0" with the objective to capture concise definitions and implementation model description. Reported definitions of Quality 4.0 refers to the blending of Industry 4.0 technologies such as Machine Learning, Artificial Intelligence, connected devices and operations, collaborative technologies such as social media and blockchain, Big Data analytics, Cloud computing, and Augmented Reality and Virtual Reality with the traditional quality management methods and approaches to achieve optimums in operational Excellence, sustaining performance, and enhancing innovation capabilities. Focus was mainly made on the Saudi industrial context, which is driven by the momentum Saudi National Vision 2030, and the National Industrial Development and Logistics Program (NIDLP).

Based on the review of the relavant research papers, a conceptual model is proposed to identify the major components of "Quality 4.0", and its implementation in the Saudi industrial context; The authors have the strong beleif that the model would need further discussion among quality researchers and excellence professionals, and indeed further research investigations within the local and global industrial context.

REFERENCES

[eBook] Quality 4.0 Impact and Strategy Handbook. (n.d.). Retrieved April 15, 2022, from https://www.lnsresearch.com/research-library/research-articles/-ebook-quality-4.0-impact-and-strategy-handbook

Armani, C. G., de Oliveira, K. F., Munhoz, I. P., & Akkari, A. C. S. (2021). Proposal and application of a framework to measure the degree of maturity in Quality 4.0: A multiple case study. In *Advances in Mathematics for Industry 4.0*. INC. https://doi.org/10.1016/b978-0-12-818906-1.00006-1

Bartodziej, C. J. (2017). The concept Industry 4.0. In *The Concept Industry 4.0*. https://doi.org/10.1007/978-3-658-16502-4_3

Dias, A. M., Carvalho, A. M., & Sampaio, P. (2021). Quality 4.0: literature review analysis, definition and impacts of the digital transformation process on quality. *International Journal of Quality and Reliability Management*, *October*. https://doi.org/10.1108/IJQRM-07-2021-0247

Forero, D. V., & Sisodia, R. (2020). *Quality 4 . 0 – How to Handle Quality in the Industry 4 . 0 Revolution Master ' s thesis in Quality and Operations Management*. *January*. https://odr.chalmers.se/bitstream/20.500.12380/300650/1/E2019_128.pdf

Gaster, L., Squires, A. J., & Crawley, J. (2003). *Providing Quality in the Public Sector:*

A Practical Approach to Improving Public Services.

Haleem, A., Javaid, M., Singh, R. P., & Suman, R. (2021). Quality 4.0 technologies to enhance traditional Chinese medicine for overcoming healthcare challenges during COVID-19. *Digital Chinese Medicine*, *4*(2), 71–80. https://doi.org/10.1016/j.dcmed.2021.06.001

Homepage: The Progress & Achievements of Saudi Arabia - Vision 2030. (n.d.). Retrieved April 15, 2022, from https://www.vision2030.gov.sa/

ISO 9000:2015(en), Quality management systems — Fundamentals and vocabulary. (n.d.). Retrieved April 15, 2022, from https://www.iso.org/obp/ui/#iso:std:iso:9000:ed-4:v1:en

Javaid, M., Haleem, A., Pratap Singh, R., & Suman, R. (2021). Significance of Quality 4.0 towards comprehensive enhancement in manufacturing sector. *Sensors International*, *2*(June), 100109. https://doi.org/10.1016/j.sintl.2021.100109

Kupper, D., Knizek, C., Ryeson, D., & Jan, N. (2019). Quality 4 . 0 Takes More Than Technology. *Boston Consulting Group (BCG)*, 1–14. https://www.bcg.com/publications/2019/quality-4.0-takes-more-than-technology

NIDLP. (2020). *National Industrial Development & Logistics Program*. Retrieved May 20, 2022, from https://www.vision2030.gov.sa/v2030/vrps/nidlp/

Palmatier, R. W., Houston, M. B., & Hulland, J. (2018). Review articles: purpose, process, and structure. *Journal of the Academy of Marketing Science*, *46*(1). https://doi.org/10.1007/S11747-017-0563-4

Pinto, C. and Romero, F (2020), “The Relationship between Quality Management and Innovation”, Proceedings of the 4th ICQEM Conference, University of Minho, Portugal, pp.259-292.

Pinto, C. and Sampaio, P. (2020), “Innovation, Technology and Quality”, Proceedings of the 4th ICQEM Conference, University of Minho, Portugal, pp.200-220.

Radziwill, N. M. (2020). Connected, intelligent, automated: the definitive guide to digital transformation and quality 4.0 (Book Review). In *Quality Management Journal* (Vol. 27, Issue 4). Quality Press. https://doi.org/10.1080/10686967.2020.1812989

Saudi Vision 2030, https://www.vision2030.gov.sa/ and https://www.vision2030.gov.sa/v2030/vrps/

Sony, M., Antony, J., & Douglas, J. A. (2020). Essential ingredients for the implementation of Quality 4.0: A narrative review of literature and future directions for research. *TQM Journal*, *32*(4), 779–793. https://doi.org/10.1108/TQM-12-2019-0275

Sony, M., Antony, J., Douglas, J. A., & McDermott, O. (2021). Motivations, barriers and readiness factors for Quality 4.0 implementation: an exploratory study. *TQM Journal*, *33*(6), 1502–1515. https://doi.org/10.1108/TQM-11-2020-0272

Zairi, M. (2017). Disrupting the Quality Profession – The Emergence of Quality 4.0. *Paper Knowledge . Toward a Media History of Documents*. http://eli-te.net/magazines-view.php?magazines_p_link=Quality-4.0-Magazine-ufa3

Zairi, M. (2019). How Quality 4.0 can be a powerful catalyst for leading ambitious transformation programs, Personal communication, 9/12/2019.

Zonnenshain, A., & Kenett, R. S. (2020). Quality 4.0—the challenging future of quality engineering. *Quality Engineering*, *32*(4), 614–626. https://doi.org/10.1080/08982112.2019.1706744

Continuous Validation of models that support Decision-Making Processes

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ABSTRACT

Purpose - New opportunities for the use of predictive models emerged with Big Data and BDA. The use of these models to support decision-making, at different levels of an organization, increases its life cycle period, and, in this case, the data that will be applied to it, continuously depart from those used in its construction and validation. It is important to understand what has been discussed about the validity of models that are used for long periods. How do assess whether improvements in the models or the data collection and transmission processes imply a significant improvement in their performance?

Design/methodology/approach - To answer these questions, the work was restricted to binary classification models, due to their simplicity and wide use. The method used was based on a systematic literature review with content analysis and the use of numerical methods.

Findings - Evidence was found that, for different areas of knowledge, validation techniques follow what is traditional in the area. Many authors state the importance of a continuous validation process, however without detailing the criteria for this practice.

Practical implications- The indices used in the validation are estimates of their real value. Future or external data may change, modifying the performance of the chosen model. In an environment increasingly impacted by predictive algorithms, the quality assurance of these results must be uninterrupted**.**

Originality/value - The quantity and size of samples are fundamental parameters for the application of Statistical Process Monitoring (SPM). In the context of continuous validation, the work discusses alternatives for the definition of these elements, an aspect not yet properly addressed in the literature.

Keywords: Kappa, Statistical Process Monitoring, DS

Paper type: General review.

1 INTRODUCTION

Since the 21st century, there has been a significant increase in the use of predictive models. This phenomenon is associated with elements present in the digital transformation of society, including Big Data and Big Data Analytics (BDA). Statistical models such as logistic regressions, multivariate linear regressions, probit models, and data-based models such as artificial neural networks, decision trees, and random forests, apply to support the decision-making of great financial impact, as well as increase the scope of applications for other areas (Çinar *et al*., 2020; Diez-Olivan *et al*., 2019; Siryani, Tanju e Eveleigh, 2017; Namdari; Jazayeri-Rad, 2014; Stetco *et al*., 2019; Santos *et al*., 2018; Joppen *et al*., 2019). This growing importance in the use of predictive models suggests the need to review current validation methods and their effectiveness.

The background of the theoretical body that sediments the paths for the application of predictive models is present in several areas of science. The current theory of the statistical modeling process has, as one of its steps, the validation of these models. Practice and theory recommend the division of data available for modeling into two blocks: the first block, containing 70% of the data, is used in the construction of the model (or model training), and the second block of data is applied in its validation (Austin, 2008; Hair *et al*., 2009; Spencer, 2014; Everitt *et al*., 2011; Li *et al.*, 2020; Du *et al*., 2021; Altman *et al*., 2009; Huang *et al*., 2018). Several metrics are proposed for this purpose, however, there is no consensus on which is the best, or most appropriate, for each application context.

Among the various predictive models, binary qualifiers are widely used due to their simplicity and relevance. A practical example of this type of model is the Covid-19 test, which classifies the individual between two categories: positive for the disease, or negative for the disease. The higher the level of hits, that is, the one classifies who is positive as positive and who is negative as negative, the higher the quality of the model. Du *et al*. (2021) created a model where low complexity blood test results (used as input variables) were applied to predict whether a particular individual is positive for covid. This predictive tool is relevant because it allows communities access to less complex and less cost-effective tests than RT-PCR. In addition to the health area, these types of models are present in the most diverse areas, such as the financial area, equipment maintenance, process control, among others (Wessler *et al.*, 2019; Daines *et al*., 2019; Li *et al*., 2020; Carvalho *et al*., 2019).

In the literature, the most usual validation procedure for these models uses indices based on the results of a cross matrix, also called the confusion or contingency matrix. Considering classification problems using only two classes (binary models), each *instance I to* be sorted is assigned to an element of the set {P, N} of positive and negative class labels (or success and failure). The matrix is composed of four basic pieces of information, illustrated in Figure 1: *i) the* TP value – true positives, indicated in the m11 position of the confusion matrix, which refers to the number of events that were classified as p (positive, success, class p, etc.) and is p; *ii)* the FP value - false positives, indicated in m12, which refers to the number of events classified as p, but which are n (negative, failures, class n, etc.); *iii)* the FN value – false negatives, indicated in m21, which refers to the number of events classified as n, but which are p; *iv)* the value TN – true negatives, indicated in m22, which refers to the number of events classified as n, and which are n; *(v)* the P value refers to the total amount of actual events p; *vi)* the value N refers to the number of actual events n; *vii)* the Pp value is the number of events classified as p; *viii)* the Np value is the number of events classified as N. Thus P + N = Pp + Np. If FN and FP = 0, we have a perfect classification, because TP = P and TN = N. Being so:

		True Class		
		P	N	Totals
Predicted class	Pp	TP m11	FP m12	TP + FP = Pp
	Np	FN m21	TN m22	FN + TN = Np
Totals		TP + FN = P	FP + TN = N	(Pp + Np) = n

Figure 1 - Confusion or Agreement Matrix
Source: adapted from Fawcett (2006)

Among the indexes are *Cohen's Kappa* (hereinafter *called Kappa*), the area under the curve of the characteristic curve of receiver operation (AUC of ROC curve), precision, recall, specificity, sensitivity (Chicco, Warrens and Jurman, 2021; Ben-David, 2008; Fawcett, 2006; Chicco e Jurman, 2020; Luque *et al,* 2019). Except for *Kappa*, the calculation formulas for these indexes will not be demonstrated, but the point is that they are all calculated based on samples from the set of instances to which the model is applied. Thus, the calculated values are estimates of the actual value of the indicator, the simple fact of taking a different sample, for the same data set, would imply a different value for the indicator.

In models used during extended time horizons, the intrinsic variability of the estimate has added the distance of the data from those applied in its elaboration. Thus, the following question is elaborated: do the validation processes guarantee the reliability of results of this class of models and the proper support to decision-making throughout its life cycle?

Seeking to understand this question, section two describes the background necessary to interpret the results, section 3 addresses the method applied in the execution of the research, and the results found are demonstrated in section 4. Conclusions and bibliographic references are described in chapters 6 and 7, respectively.

2 BACKGROUND

To give theoretical support to the development of this work, two elements were considered: Concepts of SPM and Classification error measures - Cohen's *Kappa* Index detailed in the subsequent sections.

2.1 *STATISCICAL PROCESS MONITORING - SPM*

SPM is a relevant quality tool, and, originally, its main application is in the monitoring and control of process results (Mohammadian and Amiri, 2013; Woodall and Montgomery, 2014; Mukherjee, 2015). Statistical process control (SPC) was the first method to adopt statistical techniques in the early 20th century. The most current term, called SPM, is used in the text, as it characterizes process control both by output variables (product characteristics), and input variables (process parameters).
Traditionally its implementation involves 2 Phases (Jones-Farmer *et al.*, 2017). Phase I deals with the collection and analysis of data to estimate statistical parameters, such as the mean and standard deviation, for further details on sample size it is suggested to consult (Jardim *et al.*, 2018). In this phase, the ideal situation is to know the parameter to be controlled, and its standard deviation, calculating the upper and lower control limits (UCL and LCL respectively) by Equations 1 and 2, respectively. However, these parameters are rarely available in real application situations (Chakraborti *et al.*, 2009; Woodall, 1985; Chen and Song, 2012; Oprime and Mendes, 2017). In this case, Equations 3 and 4 are applied, where θ represents the statistical parameter to be controlled, and its estimate $\hat{\theta}$.

$$UCL = \theta + h\sigma_\theta \tag{1}$$

$$LCL = \theta - h\sigma_\theta \tag{2}$$

$$\widehat{UCL} = \hat{\theta} + h\widehat{\sigma_\theta} \tag{3}$$

$$\widehat{LCL} = \hat{\theta} - h\widehat{\sigma_\theta} \tag{4}$$

The usual procedure for estimating the Phase I parameters is to take m = 25 samples of size n = 5 (Oprime and Mendes, 2017). where:

$$\hat{\theta} = \frac{1}{m}\frac{1}{n}\sum_{j=1}^{m}\sum_{i=1}^{n}\theta_{ij} \tag{5}$$

In general, h=3 in practical applications (Mohammadian e Amiri, 2013). Whereas tends to a normal distribution, statistically, this represents a theoretical bilateral confidence interval, where $\alpha = 0.0027$. The estimation of parameters interferes with the performance of the control charts, for detailed information on the use of standard deviation estimators, it is recommended to read Sobue *et al.* (2020), Jardim *et al.*(2019), Jensen *et al.*(2006).

In the initial control chart, Phase I, one´s plots the values of $\hat{\theta}$, calculated by Equation 6.

$$\hat{\theta}_m = \frac{1}{n}\sum_{i=1}^{n} \bar{\theta}_{im} \tag{6}$$

If the m values are within the established limits, it is said that the process is in control (IC), that is, the different results are due to small variations in the process (variation in environmental temperature, humidity, gradual wear of equipment), which makes economically unfeasible the actions for the reduction of this variability. If there are points outside the calculated limits (out of control points - OOC), one´s saying that the process is out of control and that special causes are interfering with the results. Unlike common causes, special causes are assignable, for example, breakage or uncalibrated equipment. In this case, actions must be taken to remove them until one´s have only common causes present and the process remains stable. At this time, new data are collected for the preparation of control charts used in Phase II of continuous monitoring $\hat{\theta}_m$ (Jones-Farmer *et al.*, 2017) . Figure 2 illustrates the identification of OOC points in the control chart.

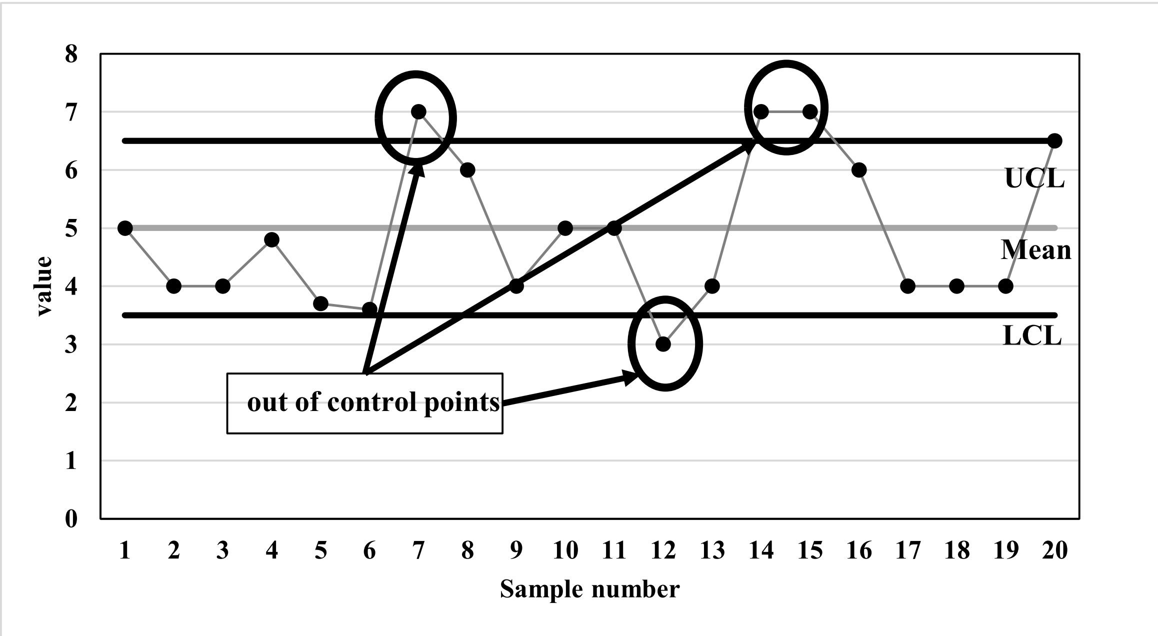

Figure 2**:** Control Chart example

The SPM is a continuous hypothesis test to assess whether the null hypothesis:

$$H_0: \hat{\theta}_m - \hat{\theta}_0 = 0$$

$$H_1: \hat{\theta}_m - \hat{\theta}_0 \neq 0$$

is true, within a certain level of confidence. As with all hypothesis testing, there are two types of errors inherent to SPM, α, and β errors. The α error is the false positive rate (when the process is under control, but the estimated value of the monitored parameter is out of limits) and the β error is the false-negative rate (when the process is out of control, but the estimated value of monitored parameter falls within limits). Specifically, concerning the expected performance of the graphics, it reflects the choice between α and β errors, with the average run length (ARL) being an important performance measure. The ARL means the number of samples that must be evaluated from a process until the occurrence of a point outside the control limits, which, in situations of process under control, is expected to be as large as possible, avoiding unnecessary stops in the process. On the other hand, in situations of an out-of-control process, one expects this value to be as small as possible, quickly identifying abnormal variations in the process. In this case, the power of the test is used to calculate the ARL. Equations 7 and 8, respectively, demonstrate these relationships. Detailed information on control charts and their performance measures can be found in the literature (Haridy *et al.*, 2011; Jensen *et al.*, 2006; Jones-Farmer *et al.*, 2017; Sobue *et al.*, 2020; Vicentin *et al.*, 2018; Woodall, 1985).

$$ARL_0 = 1/\text{a} \tag{7}$$

$$ARL_{OOC} = 1/(\text{test power}) = 1/\,(1\text{-}\ \beta) \tag{8}$$

2.2 *Classificatory errors measurement – Cohen´s Kappa*

Among the indexes used for the validation of classification models, *Kappa* is important because it excludes the effects of random correct answers, is easy to understand, and is present in several industrial applications. Equation 9 demonstrates its calculation (Cohen, 1960; Zhou, Raza, and Nelson, 2020). Based on the confusion matrix, demonstrated in Figure 1, two statistics are used in its calculation: the first, called *Po*, is the proportion of agreement of successes and failures between what is observed and predicted by the model. *Po* = (TP + TN) / (PP + NP).

The second statistic is called *Pe* and is the expected proportion of agreement of successes and failures if the classification was made randomly based on chance, and not based on the model. The calculations are detailed in Table 1 through Table 3.

$$Kappa = \frac{P_0 - P_e}{1 - P_e} \tag{9}$$

Table 1 demonstrates the confusion matrix for the example of classification into two categories (binary), where the frequencies in each of the four quadrants (TP, FP, FN, TN) are f_{xy}.

Table 1 - Confusion Matrix for *Po* Calculation

		Observed (or real)		Total
		Success	Fault	
Expected	Success	f_{11}= TP	f_{12} = FP	$T_{1.}$
	Fault	f_{21} = FN	$f_{22} = TN$	$T_{2.}$
Total		$T_{.1}$	$T_{.2}$	$T_{.1} + T_{.2}$ = n

P_0 is the observed frequency of the agreements divided by the number of observations of the data set used to validate the model, n. $P_0 = \sum P_{ii}$, Analyzing Table 2, $P_0 = P_{11} + P_{22}$.

Table 2 - Proportions based on the Confusion Matrix for *Po* Calculation

		Observed (or real)		Total
		Success	Fault	
Expected	Success	$P_{11} = \frac{f_{11}}{n}$	$P_{12} = \frac{f_{12}}{n}$	$P_{1.} = \frac{T_{1.}}{n}$
	Fault	$P_{21} = \frac{f_{21}}{n}$	$P_{22} = \frac{f_{22}}{n}$	$P_{2.} = \frac{T_{2.}}{n}$
Total		$P_{.1} = \frac{T_{.1}}{n}$	$P_{.2} = \frac{T_{.2}}{n}$	$\frac{n}{n} = 1$

The expected proportion corresponds to: $P_e = \sum P_{.i}P_{i.} = P_{.1}P_{1.} + P_{.2}P_{2.}$, as shown in Table 3.

Table 3 - Proportions based on the Confusion Matrix for *Pe* Calculation

		Observed		Total
		Success	Fault	
Expected	Success	$P_{11} = \frac{T_{1.}T_{.1}}{n^2}.$	$P_{12} = \frac{T_{1.}T_{.2}}{n^2}$	$P_{1.} = \frac{T_{1.}}{n}$
	Fault	$P_{21} = \frac{T_{2.}T_{.1}}{n^2}$	$P_{22} = \frac{T_{2.}T_{.2}}{n^2}$	$P_{2.} = \frac{T_{2.}}{n}$
Total		$P_{.1} = \frac{T_{.1}}{n}$	$P_{.2} = \frac{T_{.2}}{n}$	$\frac{n}{n} = 1$

3 RESEARCH METHODOLOGY

The work was based on three elements: analysis of the main bibliographic references, intending to list concepts related to validation processes, in general; Systematic Literature Review (SLR) to better Understand validation processes involving models applied during longer time horizons; content analysis and establishment of possible relationships with continuous improvement tools applied in the field of Production Engineering. Figure 3 illustrates the steps applied to the research.

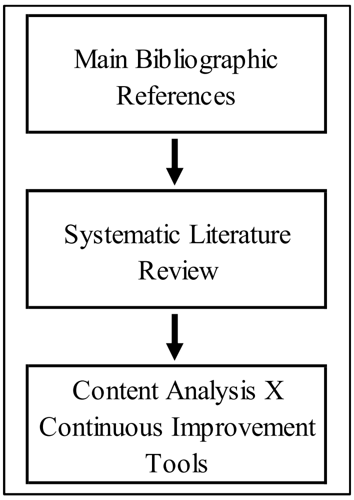

Figure 3 - Steps applied to Search

Scopus and Web of Science (WoS) databases were used on 30/11/20 and 01/12/20, respectively. In both, no date limits were applied, searching the terms in the titles, abstracts and topics, with the following string:

- (("continuous monitoring" AND KDD) OR "continuous validation" OR "temporal validation" OR ("concept drift" AND "continuous validation") OR ("statistical process monitoring" AND "model validation")) OR ("statistical process control" AND "model validation"))

In the string, the terms statistical process monitoring, and statistical process control were included according to adherence to the continuous validation theme, identified during the exploratory step to define the search terms.

For the selection of the most relevant articles, the following filters were chosen: the first filter applied was the analysis of the articles contained in both databases, thus removing the duplicate documents; the second filter eliminated all texts that did not belong to the article classification or review; the third filter was applied after the complete reading of the titles and abstracts since few studies address the theme in a specific way, most authors state the importance of adequate validation, but the specific focus of the articles are the models and variables studied, and not the validation process. Both bases allowed the creation of alerts, monitoring the occurrence of new relevant articles on the subject.

4 RESULTS

4.1 *SLR*

Altman *et al*. (2009) classify validation processes into internal, temporal, and external validation. In internal validation, a part of the available database is segregated, usually 30%, and later used for evaluation of the model (created from the 70% not segregated for validation). According to the same author, the more separated these data, the better, because it reduces the effect of super adjustment, a situation in which the model fits very well to the data used in its creation, but not to future data (Hoffmann *et al*., 2019; Fawcett; provost, 2013; Rajamanickam *et al*., 2021). In reduced databases, cross-validation or bootstrapping techniques can be used to expand the samples (Rajamanickam *et al*., 2021). Another term used is temporal validation, in this, the criterion for segregation between the data block for the elaboration of the model and the block for performance evaluation is based on the sampling period (König *et al*., 2007; Itaya *et al*., 2022). For the authors, this type of strategy is intermediate between internal and external validation, in which similar data are collected from sources different from those of the data used in the elaboration of the model. Minne *et al*. (2012b) use the same classification and define the term apparent validation in which the performance of the model is evaluated with the data used in its elaboration. Van Vliet *et al*. (2016) use the term calibration for the adjustment of parameters of existing models when the context in which it is applied is different from the context of its development. This author classifies these methods into expert knowledge-based, manual calibration, automated calibration processes, and statistical analysis. Woolley *et al*.(2012) apply the terms test and validation as synonyms stating that these processes must be executed with independent data, *i.e*., external data.

In the area of health König *et al*. (2007) evaluates the performance of a model according to its accuracy and generalization. Similarly, Parady, Ory, and Walker (2021) organize the validation criteria most applied to transport models, stating that greater attention should be paid to the validation processes of the area models. This organization is presented in Figure 4.

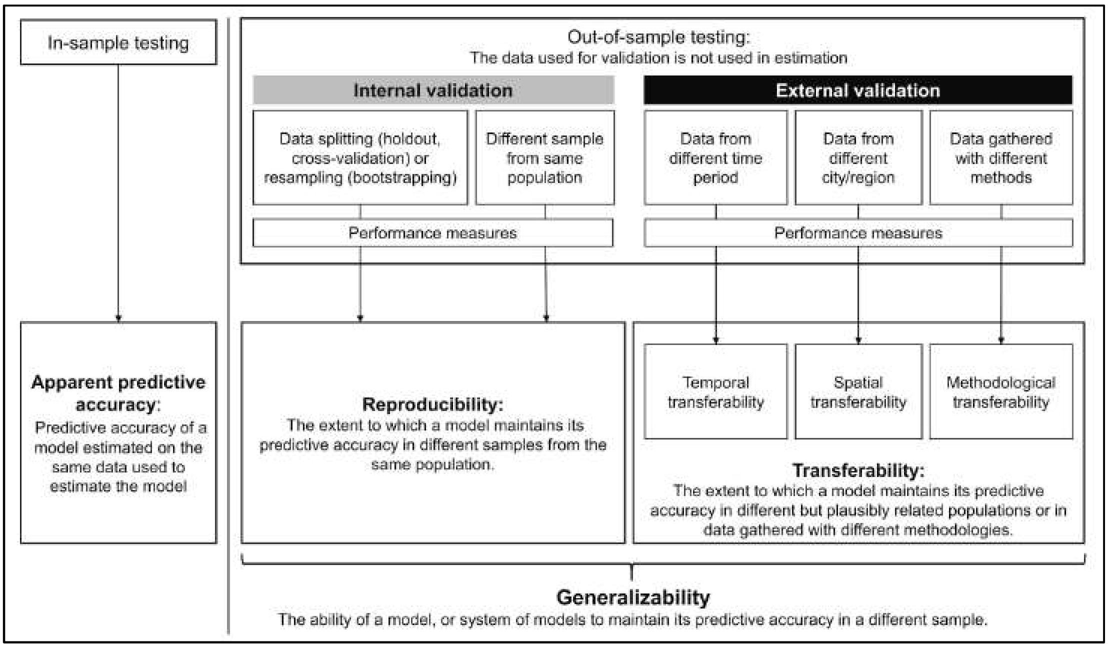

Figure 4 - Generalization as the objective of validation of statistical models
Source: Parady, Ory, and Walker (2021)

For a better understanding of the concept of temporal transferability, the SLR defined in section 3 was performed. The first filter was applied reducing from 624 to 376 papers. The second filter eliminated all texts that did not belong to article or review classification, eliminating 129 more documents. For the remaining 247 documents, abstracts were analyzed, excluding 107 articles that referred to conditions outside the scope, such as document validation, software validation, equipment, or sensor validation. Figure 5 illustrates the application of the filters that selected 140 articles.

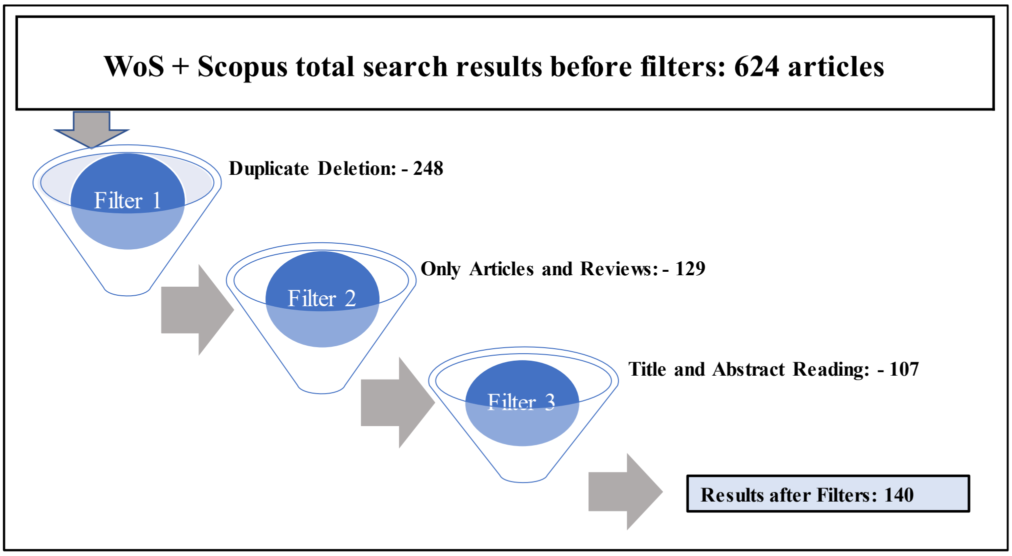

Figure 5 - Search results

Of these 140 selected articles, 30 were published until 2011 and 110 from 2012 to 2020. This evolution of publications supports the proposition already elaborated on the increase in the importance of the use of predictive models. Table 4 shows that most of the studies analyzed belong to the health area.

Table 4- Works by area of knowledge

Área	Number or Articles
Health	107
Ecology	20
Hidrology	3
Agricultural	2
Computing	1
Energy	1
Sports	1
Pharmaceutical	1
Geophysics	1
Marketing	1
Chemistry	1
Water Resources	1
Total	**140**

The term temporal validation was used in 107 articles, all in agreement with the concept presented in Figure 4. Regarding modeling techniques, logistic regression is the predominant tool, being cited or applied in 39 studies. The most applied performance index is called the area under the curve of the characteristic curve of the receiver operation (AUC of ROC curve), present in 59 studies, which will henceforth be simplified by the acronym AUC.

The importance of effective validation processes is discussed by Lang and Bolton (1991a) and Lang and Bolton (1991b) for bioanalytical methods. Although their object of study is not a classification model, these authors use control charts to continuously validate the quality of the results generated by precision chemical analysis, demonstrating the importance of monitoring variations, even in very controlled environments, such as analytical chemistry. In the field of DS, Sornette *et al*. (2007) state that a model is progressively validated by confirming repeated predictions, thus suggesting the need for statistical monitoring. In the field of machine learning. Kuncheva (2009) analyzes issues related to the detection of concept drift, which occurs when a given behavior is no longer adequately predicted by the prediction algorithm, for example, when a given loan borrower profile changes from non-defaulting to defaulting, due to changes in social conditions. The author analyzes standard control graphs for detecting these variations, however it does not justify the size and quantity of samples chosen in the analyses. In the area of health, Minne *et al*., 2012a, Minne *et al*., 2012b, and Minne *et al.*, 2012c, use control charts to compare different validation indices, also without justifying the sample sizes chosen or discussing relevant aspects of Phases I and II of the SPM, stating that studies should be done in this sense.

Cintolo-Gonzalez *et al.* (2017) and Dijkland *et al.* (2020) analyzed several prediction models and concluded that continuous validation is an important tool for implementing improvements to the algorithms created. Su *et al*. (2018) state that the performance of prediction models can deteriorate over time, and it is necessary to constantly monitor their results.

Huang *et al*. (2017) demonstrated the variability of the prediction results between different models over different periods, stating that a single measure of predictive quality is not sufficient, because estimates change according to the samples used in their calculation.

Feidas *et al*. (2018) evaluate weather models at various times in time. Hoffmann *et al*. (2019) demonstrate the relevance of continuous validation by stating that any indices used to characterize the quality of a model are estimates of the actual value of the population, since they are calculated based on samples, and should be defined according to a confidence interval.

As a continuous validation process, Chikushi *et al.* (2020) propose automatic methods of calibration, or continuous exchange of algorithms, depending on the variation of its predictive performance. Depending on the scenario this may be an appropriate approach, but this "black box" can also hide problems from the decision-making process, such as the quality of the input data. Variations causes should be diagnosed, analyzed, and treated. Changing, or recalibrating the model, can improve predictive performance momentarily, but it does not help in understanding the reasons for the quality variations of forecasts.

Finally, Oduro *et al*. (2016) and Myllyaho *et al*. (2021) state that the dynamism of the environments outsources the models, suggesting that they are continuously validated.

Regarding the input data of the model under preparation, its continuous validation is also a relevant issue (Schmidt *et al*., 2015; Munkholm *et al*., 2015; Foley and Collins, 2013; *M*anniën *et al*., 2007; Spokoiny e Shahar, 2007; Jerntorp e Berglund, 1992; Toole *et al*., 1989).

In many articles, the authors state that the constant verification of predictive quality is a relevant issue, however, they do not define fundamental criteria for its implementation, such as frequency of validation, sample size, and criteria that indicate the time when it is necessary to review the model, or review of other elements that interfere in the prediction process (Dijkland *et al*., 2020; Huang *et al*., 2018; Yin *et al*., 2017; Haltia *et al*., 2014; Katanoda *et al*., 2014; Richter *et al*., 2014; Malan *et al*., 2004; Cheong, de Gregorio e Kim, 2010; Bolaños-Sanchez, Sanchez-Arcilla e Cateura, 2007; Kaufman *et al*., 1997; Oduro *et al*., 2016; Van Vliet *et al*., 2016; Su *et al*., 2018; Hoffmann *et al*., 2019; Cintolo-Gonzalez *et al*., 2017; Kakosimos *et al.*, 2010; Coelho *et al.*, 2016)

The few studies that defined a frequency for validation were those of Chu *et al*. (2011) on precipitation estimates based on satellite information; Feidas *et al*. (2018) on the quality of forecasting rainfall indexes monthly; Katanoda *et al*. (2014) on the annual check of the forecast quality of incidence cancer models in the Japan population.

It is noticed that the subject is still open and there is much to be researched about the continuous validation of models in which most articles report their importance as an instrument to guarantee the pattern of results. The following section discusses the application of SPM in this context, a technique for reducing variations and supporting the improvement of processes.

4.2 *SPM and Kappa as an instrument of continuous improvement*

The definition of the number of samples (m) and the size of samples (n) is part of the data required for the deployment of the SPM. In Phase I, the control limits are calculated according to Equations 3 and 4, because the population parameters are rarely known, making it necessary to use estimates. In Phase II the process is monitored periodically by the extraction of n samples, calculation of the quality characteristic, and monitoring it by the control graph elaborated in Phase I.

The proposal is to use the *Kappa value* as a characteristic of the quality to be monitored. Thus, numerical simulations based on Python programming were used for the definition of sample sizes m and n. The program created has expanded a labeled database to millions of records, in this one of the variables is the experience time of an employee (independent or explanatory variable) and the other is the result of success or failure in performing their tasks (dependent variable or label). To the expanded data was applied a logistic regression model (elaborated with the initial data, not expanded), to predict, based on the variable experience, the success or failure of the employee in the execution of the task. Knowing the actual and predicted value, it became possible to calculate many confusion matrices (Figure 1), and their respective *Kappa* values (Equation 9), as a function of different values of n. Figure 6 demonstrates the normality of *Kappa* values as a function of m and n, for each graph 1000 *Kappa* values were simulated.

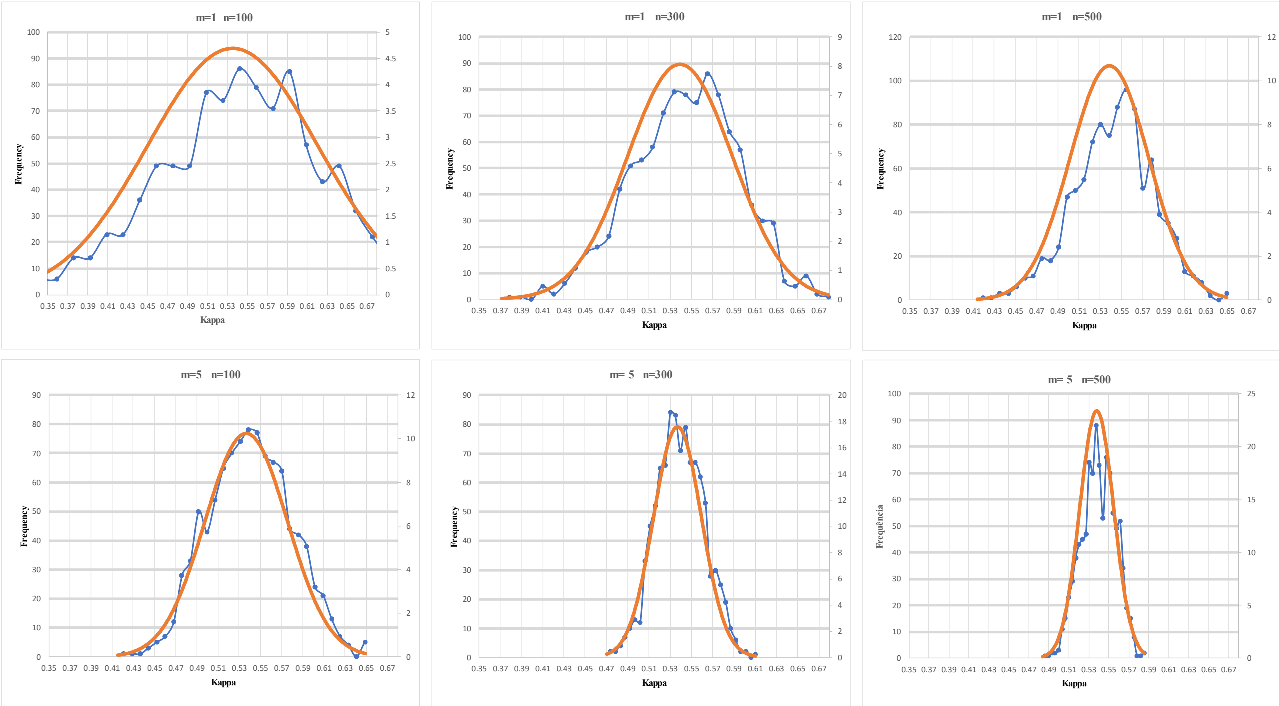

Figure 6 - Kappa normality analysis as a function of m and n
Source: Author Himself

From this logic, the program is designed to generate control limits from any m value chosen. To exemplify, if m=5 and n=100, the program generates 500 records, calculates five confusion matrices with 100 elements each, calculates their respective 5 *Kappa* values, and the control limits of Phase I. Once the control limits are defined, the simulation generates *Kappa* values until an OOC point occurs. The number of values generated until this event is called run length (RL). This procedure is repeated one hundred times. The average value of these 100 RLs is the ARL. Again, the entire procedure is repeated fifty times, that is, fifty different control limits, and therefore fifty different ARLs are calculated. The average of the 50 ARLs is called AARL (average average run length). AARL is used to reduce the estimation error.

As the control limits were calculated with h=3, the theoretical ARL, given by Equation 7, should be 370. This value was found in the simulations with m ≥ 50 e n ≥ 100. However intermediate values such as m ≥ 5 and n ≥ 300 are applicable because the AARL is close to 300. The program was also designed to include disturbances (simulating out-of-control situations) in the prediction process. For m ≥ 5 and n ≥ 300 simulations demonstrated that AARL rapidly approaches 1, as the disturbances increases. This is desirable because, in an out-of-control condition, AARL is expected to be as small as possible.

The simulations involved the creation of several scenarios, here only the summarized results were presented because the objective was to demonstrate that the *Kappa,* integrated with the SPM, properly sized, provides accurate information to identify when the validation results of a predictive process show significant variations, represented by its values below the control limits. In contrast, *Kappa* values above the control limits mean that the predictive process is performing better, which should also be evaluated, however, to ensure that this superior performance will be maintained.

The term predictive process was used because variations in K*appa* results do not necessarily mean the model has become inadequate. The root cause of the variations may be another, such as failure in the transmission of data or human errors, and should be evaluated before the revision of the model. Thus, continuous validation, in the proposed way, is configured as a process that provides information for the study of continuous improvements, or Kaizen, of the decision-making process it supports.

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6 CONCLUSIONS

It was shown that the application of external data is important in the validation processes and that variations in the quality of predictions may be due to problems in the collection and transmission of data or due to changes in operating conditions, called concept drift. In addition, the validation metrics used, for example, *Kappa*, are estimates of a real value, so they are subject to variations due to their error. Thus, it is believed that, despite the increasing use of predictive models in support of decision-making, validation processes, in general, are restricted to the punctual evaluation of the models created and the proposals for continuous validation of these models lack criteria for their implementation.

The use of SPM in this context fills this gap and allows identifying when the variation is the result of the error of estimation and when the variation is due to other causes, called special causes.

The use of simulation techniques, applied to *Kappa* integrated to the SPM, proved to be adequate to assist in the process of choosing the quantity and size of the samples. Further studies will be elaborated on in future work, since the database used had a 40% real probability of success, and it is known that *Kappa* performs differently in unbalanced databases.

7 REFERENCES

Altman, D.G., Vergouwe, Y., Royston, P. e Moons, K.G.M. (2009), “Prognosis and prognostic research: Validating a prognostic model”, *BMJ (Online)*, Vol. 338 No. 605, p. 1432–1435.

Ben-David, A. (2008), “About the relationship between ROC curves and Cohen’s kappa”, *Engineering Applications of Artificial Intelligence*, Vol. 21 No. 6, p. 874–882.

Bolaños-Sanchez, R., Sanchez-Arcilla, A. e Cateura, J. (2007), “Evaluation of two atmospheric models for wind-wave modelling in the NW Mediterranean”, *Journal of Marine Systems*, Vol. 65, p. 336–353.

Carvalho, T.P., Soares, F.A.A.M.N., Vita, R., Francisco, R. da P., Basto, J.P. e Alcalá, S.G.S. (2019), “A systematic literature review of machine learning methods applied to predictive maintenance”, *Computers and Industrial Engineering*, Elsevier, Vol. 137 , p. 10.

Chakraborti, S., Human, S.W. e Graham, M.A. (2009), “Phase I statistical process control charts: An overview and some results”, *Quality Engineering*, Vol. 21 No. 1, p. 52–62.

Chen, Y.C. e Song, W.T. (2012), “The effects of sample sizes in phases i and ii on control chart performance”, *Communications in Statistics - Theory and Methods*, Vol. 41 No. 22, p. 4047–4068.

Cheong, Y., de Gregorio, F. e Kim, K. (2010), “The power of reach and frequency in the age of digital advertising: Offline and online media demand different metrics”, *Journal of Advertising Research*, Vol. 50 No. 4, p. 403–415.

Chicco, D. e Jurman, G. (2020), “The advantages of the Matthews correlation coefficient (MCC) over F1 score and accuracy in binary classification evaluation”, *BMC Genomics*, BMC Genomics, Vol. 21 No. 1, p. 1–13.

Chicco, D., Warrens, M.J. e Jurman, G. (2021), “The Matthews correlation coefficient (MCC) is more informative than Cohen’s Kappa and Brier score in binary classification assessment”, *IEEE Access*, Vol. 9 No. Mcc, available at:https://doi.org/10.1109/ACCESS.2021.3084050.

Chikushi, R.T.M., Barros, R.S.M. de, Silva, M.G.N.M. da e Maciel, B.I.F. (2020), “Using spectral entropy and bernoulli map to handle concept drift”, *Expert Systems with Applications*, Elsevier Ltd, available at:https://doi.org/10.1016/j.eswa.2020.114114.

Chu, D., Pubu, T., Norbu, G., Sagar, B., Mandira, S. e Guo, J. (2011), “Validation of the satellite-derived rainfall estimates over the tibet”, *Acta Meteorologica Sinica*, Vol. 25 No. 6, p. 734–741.

Çinar, Z.M., Nuhu, A.A., Zeeshan, Q., Korhan, O., Asmael, M. e Safaei, B. (2020), “Machine learning in predictive maintenance towards sustainable smart manufacturing in industry 4.0”, *Sustainability (Switzerland)*, Vol. 12 No. 19, available at:https://doi.org/10.3390/su12198211.

Cintolo-Gonzalez, J.A., Braun, D., Blackford, A.L., Mazzola, E., Acar, A., Plichta, J.K., Griffin, M., *et al.* (2017), "Breast cancer risk models: a comprehensive overview of existing models, validation, and clinical applications", *Breast Cancer Research and Treatment*, Springer US, Vol. 164 No. 2, p. 263–284.

Coelho, V.N., Coelho, I.M., Coelho, B.N., Reis, A.J.R., Enayatifar, R., Souza, M.J.F. e Guimarães, F.G. (2016), "A self-adaptive evolutionary fuzzy model for load forecasting problems on smart grid environment", *Applied Energy*, Elsevier Ltd, Vol. 169, p. 567–584.

Cohen, J. (1960), "A coefficient of agreement for nominal scales", *Educational and Psychological Measurement*, Vol. 20 No. 1, p. 37-46 ST-A coefficient of agreement for nominal.

Daines, L., McLean, S., Buelo, A., Lewis, S., Sheikh, A. e Pinnock, H. (2019), "Systematic review of clinical prediction models to support the diagnosis of asthma in primary care", *npj Primary Care Respiratory Medicine*, Springer US, Vol. 29 No. 1, p. 1–9.

Diez-olivan, A., Del, J., Galar, D. e Sierra, B. (2019), "Data fusion and machine learning for industrial prognosis : Trends and perspectives towards Industry 4 . 0", *Information Fusion*, Elsevier B.V., Vol. 50 No. October 2018, p. 92–111.

Dijkland, S.A., Foks, K.A., Polinder, S., Dippel, D.W.J., Maas, A.I.R., Lingsma, H.F. e Steyerberg, E.W. (2020), "Prognosis in moderate and severe traumatic brain injury: A systematic review of contemporary models and validation studies", *Journal of Neurotrauma*, Vol. 37 No. 1, p. 1–13.

Du, R., Tsougenis, E.D., Ho, J.W.K., Chan, J.K.Y., Chiu, K.W.H., Fang, B.X.H., Ng, M.Y., *et al.* (2021), "Machine learning application for the prediction of SARS-CoV-2 infection using blood tests and chest radiograph", *Scientific Reports*, Nature Publishing Group UK, Vol. 11 No. 1, p. 1–13.

Everitt, B.S., Landau, S., Leese, M. e Stahl, D. (2011), *Cluster Analysis*, organizado por Balding, D.J., Cressie, N.A.C., Fitzmaurice, G.M., Goldstein, H., Molenberghs, G., Scott, D.W., Smith, A.F.M., et al., 5th ed., Wiley & Sons Ltd, London.

Fawcett, T. (2006), "An introduction to ROC analysis", *Pattern Recognition Letters*, Vol. 27 No. 8, p. 861–874.

Fawcett, T. e Provost, F. (2013), "Data Science and Its Relationship to Big Data and Data-Driven Decision Making Data Science", *Big Data*, No. 1, p. 51–59.

Feidas, H., Porcu, F., Puca, S., Rinollo, A., Lagouvardos, C. e Kotroni, V. (2018), "Validation of the H-SAF precipitation product H03 over Greece using rain gauge data", *Theoretical and Applied Climatology*, Theoretical and Applied Climatology, Vol. 131 No. 1–2, p. 377–398.

Foley, R.N. e Collins, A.J. (2013), “The USRDS: What you need to know about what it can and can’t tell us about ESRD”, *Clinical Journal of the American Society of Nephrology*, Vol. 8 No. 5, p. 845–851.

Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E. e Tatham, R.L. (2009), *Análise Multivariada de Dados*, 6ª edição., Bookman, Porto Alegre, available at:https://doi.org/0-13-032929-0.

Haltia, U.-M., Bützow, R., Leminen, A. e Loukovaara, M. (2014), “FIGO 1988 versus 2009 staging for endometrial carcinoma: A comparative study on prediction of survival and stage distribution according to histologic subtype”, *Journal of Gynecologic Oncology*, Vol. 25 No. 1, p. 30–35.

Haridy, S., Wu, Z. e Castagliola, P. (2011), “Univariate and multivariate approaches for evaluating the capability of dynamic-behavior processes (case study)”, *Statistical Methodology*, Elsevier B.V., Vol. 8 No. 2, p. 185–203.

Hoffmann, F., Bertram, T., Mikut, R., Reischl, M. e Nelles, O. (2019), “Benchmarking in classification and regression”, *Wiley Interdisciplinary Reviews: Data Mining and Knowledge Discovery*, Vol. 9 No. 5, p. 1–17.

Huang, C., Murugiah, K., Mahajan, S., Li, S.-X., Dhruva, S.S., Haimovich, J.S., Wang, Y., *et al.* (2018), “Enhancing the prediction of acute kidney injury risk after percutaneous coronary intervention using machine learning techniques: A retrospective cohort study”, *PLoS Medicine*, Vol. 15 No. 11, available at:https://doi.org/10.1371/journal.pmed.1002703.

Huang, T., Mi, H., Lin, C.-Y., Zhao, L., Zhong, L.L.D., Liu, F.-B., Zhang, G., *et al.* (2017), “MOST: Most-similar ligand based approach to target prediction”, *BMC Bioinformatics*, Vol. 18 No. 1, available at:https://doi.org/10.1186/s12859-017-1586-z.

Itaya, T., Murakami, Y., Ota, A., Shimomura, R., Fukushima, T. e Nishigaki, M. (2022), “Temporal Validation of an Assessment Tool that Predicts a Possibility of Home Discharge for Patients with Acute Stroke”, *Journal of Stroke and Cerebrovascular Diseases*, Elsevier Inc., Vol. 31 No. 1, p. 106188.

Jardim, F.S., Chakraborti, S. e Epprecht, E.K. (2018), “effect of the amount of phase I data on the conditional performance of phase II Xb¯chart”.

Jardim, F.S., Chakraborti, S. e Epprecht, E.K. (2019), “X¯ Chart with Estimated Parameters: The Conditional ARL Distribution and New Insights”, *Production and Operations Management*, Vol. 0 No. 0, p. 1–13.

Jensen, W.A., Jones-farmer, L.A., Champ, C.W. e Woodall, W.H. (2006), “Effects of Parameter Estimation on Control Chart Properties : A Literature Review”, *Journal of Quality Technology*, Vol.

38 No. 4, p. 349–364.

Jerntorp, P. e Berglund, G. (1992), “Stroke registry in Malmö, Sweden”, *Stroke*, Vol. 23 No. 3, p. 357–361.

Jones-Farmer, L.A., Woodall, W.H., Steiner, S.H. e Champ, C.W. (2017), “An Overview of Phase I Analysis for Process Improvement and Monitoring”, *Journal of Quality Technology*, Vol. 46 No. 3, p. 265–280.

Joppen, R., Enzberg, S. von, Gundlach, J., Kühn, A. e Dumitrescu, R. (2019), “Key performance indicators in the production of the future”, *Procedia CIRP*, Elsevier B.V., Vol. 81, p. 759–764.

Kakosimos, K.E., Hertel, O., Ketzel, M. e Berkowicz, R. (2010), “Operational Street Pollution Model (OSPM) - A review of performed application and validation studies, and future prospects”, *Environmental Chemistry*, Vol. 7 No. 6, p. 485–503.

Katanoda, K., Kamo, K.-I., Saika, K., Matsuda, T., Shibata, A., Matsuda, A., Nishino, Y., *et al.* (2014), “Short-Term projection of cancer incidence in Japan using an age-period interaction model with spline smoothing”, *Japanese Journal of Clinical Oncology*, Vol. 44 No. 1, p. 36–41.

Kaufman, Y.J., Tanré, D., Gordon, H.R., Nakajima, T., Lenoble, J., Frouin, R., Grassl, H., *et al.* (1997), “Passive remote sensing of tropospheric aerosol and atmospheric correction for the aerosol effect”, *Journal of Geophysical Research Atmospheres*, Vol. 102 No. 14, p. 16815–16830.

König, I.R., Malley, J.D., Weimar, C., Diener, H.-C. e Ziegler, A. (2007), “Practical experiences on the necessity of external validation”, *Statistics in Medicine*, Vol. 26, p. 5499–5511.

Kuncheva, L.L. (2009), “Using control charts for detecting concept change in streaming data”, *School of Computer Science, Bangor University, …*, p. 1–13.

Lang, J.R. e Bolton, S. (1991a), “A comprehensive method validation strategy for bioanalytical applications in the pharmaceutical industry - 2. Statistical analyses”, *Journal of Pharmaceutical and Biomedical Analysis*, Vol. 9 No. 5, p. 357–361.

Lang, J.R. e Bolton, S. (1991b), “A comprehensive method validation strategy for bioanalytical applications in the pharmaceutical industry -1. Statistical analyses”, *Journal of Pharmaceutical and Biomedical Analysis*, Vol. 9 No. 6, p. 435–442.

Li, J.P., Mirza, N., Rahat, B. e Xiong, D. (2020), “Machine learning and credit ratings prediction in the age of fourth industrial revolution”, *Technological Forecasting and Social Change*, Elsevier, Vol. 161 No. September, p. 120309.

Luque, A., Carrasco, A., Martín, A. e de las Heras, A. (2019), “The impact of class imbalance in classification performance metrics based on the binary confusion matrix", *Pattern Recognition*, Elsevier Ltd, Vol. 91, p. 216–231.

Malan, A.K., Martins, T.B., Hill, H.R. e Litwin, C.M. (2004), "Evaluations of Commercial West Nile Virus Immunoglobulin G (IgG) and IgM Enzyme Immunoassays Show the Value of Continuous Validation", *Journal of Clinical Microbiology*, Vol. 42 No. 2, p. 727–733.

Manniën, J., van der Zeeuw, A.E., Wille, J.C. e van den Hof, S. (2007), "Validation of Surgical Site Infection Surveillance in The Netherlands", *Infection Control & Hospital Epidemiology*, Vol. 28 No. 1, p. 36–41.

Minne, L., Eslami, S., de Keizer, N., de Jonge, E., de Rooij, S.E. e Abu-Hanna, A. (2012a), "Statistical process control for validating a classification tree model for predicting mortality - A novel approach towards temporal validation", *Journal of Biomedical Informatics*, Elsevier Inc., Vol. 45 No. 1, p. 37–44.

Minne, L., Eslami, S., de Keizer, N., de Jonge, E., de Rooij, S.E. e Abu-Hanna, A. (2012b), "Statistical process control for monitoring standardized mortality ratios of a classification tree model", *Methods of Information in Medicine*, Vol. 51 No. 4, p. 353–358.

Minne, L., Eslami, S., de Keizer, N., de Jonge, E., de Rooij, S.E. e Abu-Hanna, A. (2012c), "Effect of changes over time in the performance of a customized SAPS-II model on the quality of care assessment", *Intensive Care Medicine*, Vol. 38 No. 1, p. 40–46.

Mohammadian, F. e Amiri, A. (2013), "Economic-statistical design of acceptance control chart", *Quality and Reliability Engineering International*, Vol. 29 No. 1, p. 53–61.

Mukherjee, P.S. (2015), "On phase II monitoring of the probability distributions of univariate continuous processes", *Statistical Papers*, Vol. 57 No. 2, p. 539–562.

Munkholm, S.B., Jakobsen, C.-J., Mortensen, P.E., Lundbye-Christensen, S. e Andreasen, J.J. (2015), "Validation of post-operative atrial fibrillation in the western denmark heart registry", *Danish Medical Journal*, Vol. 62 No. 12, p. 4.

Myllyaho, L., Raatikainen, M., Männistö, T., Mikkonen, T. e Nurminen, J.K. (2021), "Systematic literature review of validation methods for AI systems", *Journal of Systems and Software*, Elsevier Inc., Vol. 181, p. 111050.

Namdari, M. e Jazayeri-rad, H. (2014), "Incipient fault diagnosis using support vector machines based on monitoring continuous decision functions", *Engineering Applications of Artificial Intelligence*, Elsevier, Vol. 28, p. 22–35.

Oduro, A.R., Maya, E.T., Akazili, J., Baiden, F., Koram, K. e Bojang, K. (2016), "Monitoring malaria using health facility based surveys: Challenges and limitations", *BMC Public Health*, Vol. 16 No. 1, available at:https://doi.org/10.1186/s12889-016-2858-7.

Oprime, P.C. e Mendes, G.H. de S. (2017), "The X-bar control chart with restriction of the capability indices", *International Journal of Quality and Reliability Management*, Vol. 34 No. 1, p. 38–52.

Parady, G., Ory, D. e Walker, J. (2021), "The overreliance on statistical goodness-of-fit and under-reliance on model validation in discrete choice models: A review of validation practices in the transportation academic literature", *Journal of Choice Modelling*, Elsevier Ltd, Vol. 38 No. February 2020, p. 100257.

Rajamanickam, V., Babel, H., Montano-herrera, L., Ehsani, A. e Stiefel, F. (2021), "About Model Validation in Bioprocessing", *Processes*, p. 1–16.

Richter, A., Weber, M., Burrows, J.P., Lambert, J.C. e Van Gijsel, A. (2014), "Validation strategy for satellite observations of tropospheric reactive gases", *Annals of Geophysics*, Vol. 56 No. FAST TRACK 1, p. 1–10.

Santos, L., Brittes, G., Fabián, N. e Germán, A. (2018), "The expected contribution of Industry 4 . 0 technologies for industrial performance", *Intern. Journal of Production Economics*, Elsevier B.V., Vol. 204 No. August, p. 383–394.

Schmidt, M., Schmidt, S.A.J., Sandegaard, J.L., Ehrenstein, V., Pedersen, L. e Sørensen, H.T. (2015), "The Danish National patient registry: A review of content, data quality, and research potential", *Clinical Epidemiology*, Vol. 7, p. 449–490.

Siryani, J., Tanju, B. e Eveleigh, T.J. (2017), "A Machine Learning Decision-Support System Improves the Internet of Things' Smart Meter Operations", *IEEE Internet of Things Journal*, Vol. 4 No. 4, p. 1056–1066.

Sobue, F., Eduardo, C., Jardim, F.S., Camargo, V.C.B., Lizarelli, F.L. e Oprime, P.C. (2020), "Unconditional performance of the X¯ chart: Comparison among five standard deviation estimators", *Quality and Reliability Engineering International*, Vol. 36 No. 5, p. 1808–1819.

Sornette, D., Davis, A.B., Ide, K., Vixie, K.R., Pisarenko, V. e Kamm, J.R. (2007), "Algorithm for model validation: Theory and applications", *Proceedings of the National Academy of Sciences of the United States of America*, Vol. 104 No. 16, p. 6562–6567.

Spokoiny, A. e Shahar, Y. (2007), "An active database architecture for knowledge-based incremental abstraction of complex concepts from continuously arriving time-oriented raw data", *Journal of Intelligent Information Systems*, Vol. 28 No. 3, p. 199–231.

Stetco, A., Dinmohammadi, F., Zhao, X., Robu, V., Flynn, D., Barnes, M., Keane, J., *et al.* (2019), "Machine learning methods for wind turbine condition monitoring : A review", *Renewable Energy*, Elsevier Ltd, Vol. 133, p. 620–635.

Su, T.-L., Jaki, T., Hickey, G.L., Buchan, I. e Sperrin, M. (2018), "A review of statistical updating methods for clinical prediction models", *Statistical Methods in Medical Research*, Vol. 27 No. 1, p. 185–197.

Toole, J.F., Teagle, W.C., Howard, V.J., Grizzle, J. e Chambless, L.E. (1989), "Study design for randomized prospective trial of carotid endarterectomy for asymptomatic atherosclerosis", *Stroke*, Vol. 20 No. 7, p. 844–849.

Vicentin, D.S., Silva, B.B., Piccirillo, I., Bueno, F.C. e Oprime, P.C. (2018), "Monitoring process control chart with finite mixture probability distribution", *International Journal of Quality & Reliability Management*, Vol. 35 No. 2, p. 335–353.

Van Vliet, J., Bregt, A.K., Brown, D.G., Van Delden, H., Heckbert, S. e Verburg, P.H. (2016), "A review of current calibration and validation practices in land-change modeling", *Environmental Modelling and Software*, Elsevier Ltd, Vol. 82, p. 174–182.

Wessler, B.S., Lundquist, C.M., Koethe, B., Park, J.G., Brown, K., Williamson, T., Ajlan, M., *et al.* (2019), "Clinical Prediction Models for Valvular Heart Disease", *Journal of the American Heart Association*, Vol. 8 No. 20, p. e011972.

Woodall, W.H. (1985), "The Statistical Design of Quality Control Charts", *The Statistician*, Vol. 34 No. 2, p. 155.

Woodall, W.H. e Montgomery, D.C. (2014), "Some Current Directions in the Theory and Application of Statistical Process Monitoring", *Journal of Quality Technology*, Vol. 46 No. 1, p. 72.

Woolley, T., Shaw, D.C., Ganio, L.M. e Fitzgerald, S. (2012), "A review of logistic regression models used to predict post-fire tree mortality of western North American conifers", *International Journal Of Wildland Fire*, No. 2006, p. 1–35.

Yin, G., Li, A., Jin, H., Zhao, W., Bian, J., Qu, Y., Zeng, Y., *et al.* (2017), "Derivation of temporally continuous LAI reference maps through combining the LAINet observation system with CACAO", *Agricultural and Forest Meteorology*, Elsevier B.V., Vol. 233, p. 209–221.

Zhou, T.J., Raza, S. e Nelson, K.P. (2020), "Methods of assessing categorical agreement between correlated screening tests in clinical studies", *Journal of Applied Statistics*, Taylor & Francis, Vol. 0 No. 0, p. 1–21.

Patient experience in health care services. A gender perspective

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ABSTRACT

Purpose - The healthcare sector has dramatically changed due to the role of the patient, who has become more personally involved in their healthcare decisions. Previously, hospitals focused on saving or curing as many people as possible without regarding the patient experience. This perspective has changed, and patient satisfaction has become a milestone in the sector. Therefore, this article explores patient satisfaction in the healthcare sector by studying the emotional and utilitarian factors (sociodemographic factors, gender, and type of services).

Design/methodology/approach – To verify the hypothesis proposed, a questionnaire survey in a Portuguese healthcare service was used to collect data. 386 responses were obtained. Descriptive statistics, validity and reliability analysis, a Kruskal Wallis test, and ordinal regression analysis were used for the data analysis.

Findings – Utilitarian factors are positively related to staff behavior, access to unique treatments or discounts, involvement in the care process with complete and precise information, and level of trust in the care service. Gender does not impact these factors, while the type of service offered does. On the other hand, emotional factors such as contentment, a sense of cheerfulness, the healthcare service that matches its values and beliefs, and reasonable waiting time increase satisfaction; however, results indicate that stimulation reduces patient satisfaction. Gender and type of service both present significant differences regarding the emotional factors.

Originality/value - The article explores the patient experience by considering emotional and utilitarian factors from a gender perspective and considering the services offered by the health care service, thus reducing the lack of available studies in this context. Besides, most existing studies focus only on utilitarian factors without considering emotional aspects. The present article combines both factors (utilitarian and emotional), which enriches the existing literature with a comparative analysis. Moreover, the literature on gender analysis in the healthcare sector is minimal. Thus, the present article provides novel and relevant information on gender differences in this sector. Finally, existing research identified some factors that influence the perception of customer satisfaction, mainly utilitarian. However, the article goes beyond that notion to understand that the entire patient experience is rooted in emotional factors. In addition, more research is needed to explore why the female perspective is different.

Keywords: patient satisfaction, quality, health care sector, gender.

Paper type: Research paper

INTRODUCTION

Customer experience assessment is becoming a critical factor in guaranteeing citizens access to safe and quality healthcare services in the healthcare sector. Continuous improvement in the performance of healthcare services is considered extremely important due to the population's growing concern for their quality and for the performance of policies that are better suited to their needs. As healthcare services become more concerned about the patient experience, their reputation and image as leading centers in the market become more robust, and the patient becomes the model's center.

The literature aims to develop scales for measuring patient satisfaction in health services (Worlu et al., 2015; Pullicino et al., 2015); its objective is to adapt scales from quality in services (Jackson et al., 2020). The results are contradictory because the application of questionnaires validated with few cases or the habitual use of qualitative research methods, as reported by Pérez-Cantó et al. (2019). The literature recognizes that a customer can be satisfied with a company's product or service, just as they can be satisfied with competence (Bueno et al., 2019). However, living an experience related to a service or product is much more than satisfactory. It includes affective emotions such as the feeling of being identified with the organization, surprise, or even love.

As a result, delivering high-quality services generates positive memories (Bueno et al., 2019) or positive experiences that affect the evaluation of similar services. The literature recognizes that one of the main problems lies in the assessment of experiences and in the difficulty of identifying positive attitudes in customers. As Shen and Dillard (2007) pointed out, attitudes are defined as responses that are evaluated emotionally, cognitively, and behaviorally, ranging from positive to negative valence; while customer experience is defined by Meyer and Schwager (2007) as 'the subjective and internal responses that customers have in any direct or indirect contact with a company' (p. 2). Also, Bueno et al., 2019 concluded that these interactions evoke personal reactions that imply customer involvement at different levels: rational, emotional, sensory, physical, and spiritual (Berry et al., 2002; Mok et al., 2007). Therefore, the main objective of the present study is to evaluate the emotional factors related to the experience in health care according to sociodemographic factors, highlighting gender and the type of service (public and private).

In addition, healthcare providers have realized that they must differentiate their offerings/services. They can achieve this by providing the consumers with positive experiences (Gilmore and Pine, 2002). However, it is still unclear whether or how customer demographic variables (such as gender, education level, or family income) evaluate the dimensions of customer experience quality differently.

LITERATURE REVIEW

Customer experiences are about direct and indirect contact between customers and service providers. Bueno et al., (2019) highlight that the direct contact is usually initiated by the customer and occurs during the purchase of a product or the use of a service; while the indirect one occurs unexpectedly may be in the form of advertising, news, recommendations, or word of mouth. According to Palmer (2010), until the 1980s, approximately the definitions of customer experience were essentially about accumulating knowledge and wisdom. The later definitions emphasized experience as a unique event generating a consumer response (cognitive, affective, or behavioral). The customer experience focuses on customers as the experience actors and is described as an internal and subjective customer response (Meyer and Schwager, 2007).

The academic study of relationship marketing has given limited attention to consumers' emotional states and how those emotions could positively impact a long-term relationship with companies and service providers (Gummerus et al., 2017). Despite this, a growing body of literature has provided several findings that support the role of positive and negative emotions consumers associate with a memorable service encounter and how those encounters determine future behavioral intention (Palmer, 2010). Thus, Jain and Bagdares (2009) concluded that customer experience includes the three stages: pre-purchase, purchase, and post-purchase, considering affective and cognitive dimensions (Verhoef et al., 2009).

Because of the complexity of the service sector and specifically health services, there are multiple scales to measure the qualities related to customer experience. A literature review published by Aagja and Bagdare (2017) summarized that satisfaction and service experience are examples of constructs related to customer experience in service, generating, on many occasions' doubts about their differences (de Vasconcelos et al., 2015). However, the authors concluded that they are two complementary concepts, and other similar constructs are widely used to address this divergence.

The healthcare sector aims to improve all people's physical and mental well-being. Healthcare helps people stay healthy throughout their lives (Worlu et al., 2016).

In this study, we have considered constructs and findings in the literature to study the different experiences of both private and public healthcare services and findings in the literature. The most relevant are shown in Table 1.

Table 1 – List of dimensions and variables for patient experience in the literature

Dimension	Variable	Author	Methodology
Physical Environment	Accessibility, cleanliness, smell, lighting, noise, furniture, temperature, food, and leisure	(Bellio and Buccoliero, 2020; Zhang et al., 2006)	Mediation and moderation effects analysis
Empowerment and dignity	Involvement in the care process, complete and transparent information and privacy, and respect concerning private information	(Bellio and Buccoliero, 2020)	Mediation and moderation effects analysis
Patient–doctor Relationship/auxiliary staff	Ability to recognize medical uniforms, collaborative team attitude, and relationship with the medical staff, I sensed that other patients could listen when I was talking to the staff. I felt like one in the crowd.	(Stein et al., 2001 and Bellio and Buccoliero, 2020)	Mediation and moderation effect analysis /survey and physicometric analysis
Overall Satisfaction	Perceived security inside the hospital, degree of serenity in the hospital experience, overall evaluation of the hospital experience	(Bellio and Buccoliero, 2020)	Survey and physicometric analysis
Subjective Health Frailty	Health self-assessment and perceived outcome of care and medication	(Bellio and Buccoliero, 2020)	Mediation and moderation effects analysis
Interaction	Physician communication Interaction and staff communication	(Ozcelik and Burnaz, 2019)	Interviews
Psychology	Defines a patient's feeling of safety	(Ozcelik and Burnaz, 2019)	Interviews
Communication	I felt reassured, I felt I was Taken care of, we had a good talk, and the doctor understood what was on my mind.	(Stein et al., 2001)	Survey and physicometric analysis
Emotions	Sad-cheerful, worn out-strengthened, worried-relieved. Tense-relaxed	(Stein et al., 2001)	Survey and physicometric analysis
Outcome (short term)	Do you know what to do to reduce your health problems? Do you know what to expect from now on? Will you be able to handle your problems differently?	(Deshwal, 2016; Bellio and Buccoliero, 2020; and Zhang et al., 2006)	ANOVA test/Mediation and moderation effects analysis
Barriers	Too much time was spent on small talk, it was a bit difficult to ask questions, Important decisions were made over my head, and it was a bit difficult to connect with the doctor.	(Stein et al., 2001)	Survey and physicometric analysis

As some authors highlighted, customer experience emerges as a holistic form, not limited to the service and the service experience, and should focus on emotional and physical components (Deshwal, 2016). The scope of customer experience is broader than that of service quality, as it includes feelings and emotions that are not measured when measuring service quality. In this study, we have used various constructs from service quality (utilitarian) and emotional components to study the different patient experiences across different demographic profiles.

Westbrook and Oliver (1991) identified five different levels of satisfaction, three of which are related to positive emotions. While Parasuraman et al. (1985) state that:

- When perception exceeds expectations in a way that is considered normal, we get moderately satisfied consumers;
- When perception exceeds expectations in a way that is considered possible but unlikely, we have consumers who feel happy/content;

- When perception exceeds expectations in an improbable way given initial expectations, the consumer feels "delighted" by being surprised in a highly positive way.

Therefore, applying this theory and some of the dimensions proposed by Bellio and Buccoliero (2020), the model includes the measurement of experiential satisfaction. In addition to the dimension of perceived quality of the utilitarian factors (see Figure 1), which is essentially cognitive and includes physical environment variables. The effective approach applied comes from Plutchik's (1980) theory. Plutchik (1980) developed the psychoevolutionary theory of emotions, which model presented a set of eight primary emotions, organized in a circular diagram, these acceptance, fear, surprise, sadness, disgust, anger, and anticipation. According to Arnold et al. (2005), the combination of these emotions can give rise to more complex emotions (primary, secondary, and tertiary); that is, the interactions between the basic emotions give rise to a range of other emotions like delight, used to assess the experiential satisfaction.

In this study, we have used the two constructs to study the different experiences of patients (See Figure 1). Figure 1 shows the research model given the patient experience as "the main output coming from all the different healthcare-related elements that patients observe" (Bellio and Buccoliero, 2021, p. 177). Besides, it adds an indicator of the quality of a specific hospital (Wilson and Strong, 2014), which includes both utilitarian and emotional factors by adapting the reviewed previous studies.

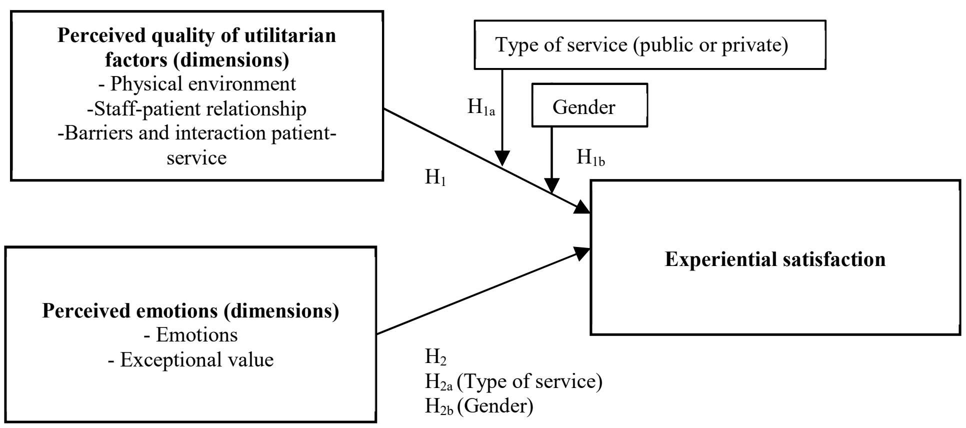

Figure 1 – Research model (the sociodemographic variables were also included in the relationship between the perceived emotions and experiential satisfaction)

From the model, we developed the following hypothesis:

H_1. The perceived quality of utilitarian factors is positively related to experiential satisfaction.

H_{1a}. The type of service impacts the positively related perception of the utilitarian factors in the patient experience.

H_{1b}. The gender of the patients impacts the positively related perception of the utilitarian factors in the patient experience.

H_2. The perceived emotions are positively related to experiential satisfaction.

H_{2a}. The type of service impacts the positively related perception of the emotions in the patient experience.

H_{2b}. The gender of the patients impacts the positively related perception of the emotions in the patient experience.

RESEARCH METHODOLOGY

Data collection and measures

A survey made the data collection with 26 items to measure patient experiences applied face-to-face in private and public healthcare services in Portugal. The survey has three sections: the first included the demographic (gender, age, nationality, educational level, area of specialization to which patients were referred, and type of servicer, whether public or private). The second section encompassed the dimensions of the perceived quality of the utilitarian factors, while the third one encompassed the perceived emotions and experiential satisfaction. Due to the survey being applied in health care services, some ethical issues were considered strictly. In any case, was requested clinical information from patients, the data analysis was global, and the survey had a volunteering character. Besides, before the survey application, the researchers met with the healthcare authorities to present the study and get their consent.

The following table includes the variables in the study, the code for each variable, the measurement scale, and references in the literature where other authors used a similar variable.

Three hundred eighty-six (n=386) patients agreed to respond to the survey. The high response rates could be reached because the face-to-face survey was designed under the rules to respond mandatorily to every question. The researchers gave respondents a good ambiance and conditions and all the time they needed to answer the questions.

Table 2 – Dimensions and variables in the study.

Dimensions	Variables	Measures	Scale
Perceived quality of utilitarian values	Physical environment	PE1: appearance, PE2: accessibility, PE3: schedule, PE4: communication, PE5: comfort, PE6: adaptation of the service to the patient's needs and preferences, and PE7: adaptation of the facilities to the patient's particular needs.	Five-point Likert scale from 1- Not good; 2- Acceptable; 3- Good; 4- Remarkable; 5- Excellent
	Staff-patient relationship	SP1: physician recommendations of care and medication, SP2: staff behavior, SP3: staff attitude,	
	Barriers and interaction patient-service	BI1: access to unique treatments or discounts, BI2: flexibility and suitability of the healthcare service, BI3: level of trust in the care service, BI4: physician and facility follow-up after care in case of issues, BI5: involvement in the care process with complete and precise information, BI6: performance of the healthcare service in response to your complaints	
Emotional factors	Emotions	EM1: contentment, EM2: peaceful, EM3: relieved, EM4: optimistic, EM5: hopeful, EM6: stimulated, EM7: cherished, EM8: surprised	Five-point Likert scale from 1- Not at all; 2- A little; 3- Moderately; 4- Quite a lot; 5- Absolutely
	Exceptional value	EV1: willingness to share the experience, EV2: the healthcare service matches my values and beliefs, EV3: willingness to share opinions about the care, EV4: reasonable awaiting the time	Five-point Likert scale from 1-Strongly disagree; 2- Disagree; 3- Neither agree nor disagree; 4- Agree; 5- Strongly agree
	Experiential satisfaction	EX1: Satisfaction	Satisfied, more than satisfied, delighted

Statistical analysis

The SPSS statistical software (version 25.0) was adopted to analyze the data collected. The first step consisted of pre-treatment of the data and the study of normality, measures of central tendency, and dispersion. As a second step, the reliability and validity of the survey were studied.

The reliability and validity were used using Cronbach's Alpha coefficient and the Kaiser-Meyer-Olkin test (KMO). Cronbach's Alpha coefficient is the most widely used method to evaluate the internal consistency (homogeneity of the items) of a set of variables and reliability analysis (if the values obtained do not present errors). According to Hair et al. (2009), the Alpha value ranges between 0 and 1. It considers a reasonable internal consistency of the factors when the value is higher than 0.70.

While the Kaiser-Meyer-Olkin test (KMO) is a statistical technique that varies between 0 and 1 and indicates the proportion of variability in the data considering common to all variables. According to Pestana and Gageiro (2008), when partial correlations are small, the KMO value is close to 1, indicating the suitability of the data for factor analysis. The KMO and Bartlett's test are two statistical procedures that allow the quality of correlations between variables to be evaluated.

Because of the variables' nature, the Rho coefficient was applied in Spearman's test to assess a bivariate correlation among variables in each dimension. As indicated in the survey, customers were asked for the type of service and the area experience among the alternatives (medical appointment, medical exam, medical treatment, medical emergency, or other reasons). Therefore, the Mann-Whitney test was used to achieve differences between the utilitarian and emotional factors and the experiential satisfaction and between the demographic's variables and the mean scores with the variables in the study. The use of the test supposes the comparison of two independent samples; therefore, the options were grouped into main sectors: type of service (private or public) and gender (male or female).

This paper proposes a model tested by estimating the ordinal logistic regression model (ORL). ORL is the appropriate regression analysis to perform when the nature of the dependent variables is categorical (Osborne, 2015). This model is an alternative to a discriminant analysis when the normal model is not applicable. According to Bozpolat (2016), the main objective of logistic regression analysis is to establish an acceptable model with a good fit that can identify the relationship between the predicting and predicted variables by using a minimum number of variables (Manresa and Escobar, 2021).

RESULTS

Sample characteristics and descriptive statistics

Three hundred eighty-six (n=386) patients participated in the study; demographic variables and characteristics of the sample are explained in Table 3. The sample includes more than 92.48% of respondents from Portugal, and 46.37% are between 31 and 40 years old. About the assessment of the experiential satisfaction, half of the sample was more than satisfied, and more than 21% recognized a state of delight in the experience.

Table 3 – Description of the demographic variables.

Variable	Description	% (n)
Gender	Male	66.32 (256)
	Female	33.68 (130)
Age group	<20 years old	1.6 (6)
	21-30 years old	21.2 (82)
	31-40 years old	46.4 (179)
	41-50 years old	18.9 (73)
	51-60 years old	5.7 (22)
	>61 years old	6.2 (24)
Educational level	Without studies	0.3 (1)
	Basic education	5.4 (21)
	Secondary education	33.2 (128)
	Bachelor degree	41.2 (159)
	Postgraduation studies	18.4 (71)
	PhD	1.6 (6)
Type of sector	Public	51.6 (199)
	Private	48.4 (187)
Area of specialization	Medical appointment	36.5 (141)
	Medical emergency	31.3 (121)
	Medical exams	9.3 (36)
	Medical treatment	8 (31)
	Other	14.8 (57)
Experiential satisfaction	Satisfied patients	18.7(72)
	More than satisfied patients	50(193)
	Delighted patients	21.3(121)

Reliability and validity analysis

A reliability and validity analysis of the scale used was carried out, considering each dimension. As stated in Table 2, the dimensions studied were Perceived quality of utilitarian values (composed of Physical environment, Staff-patient relationship, and Barriers and interactions between patient-service) and Emotional factors (composed of Emotions, Exceptional value, and Experiential satisfaction). Table 4 shows the result of Barlett's test of sphericity (KMO) and Cronbach's Alpha measures. The results indicate positive Cronbach's Alpha values between 0.950 and 0.954 (for both utilitarian values and emotional factors, respectively), suggesting a good internal consistency of the instrument. The KMO values vary between 0.938 and 0.959 (p=0.001), indicating a good correlation between the variables used.

Table 4 – Reliability and validity analysis.

Dimension	Alfa de Cronbach (α)	KMO	Significance	Accumulative Explained variance (%)
Perceived quality of utilitarian values	0.954	0.959	<0.001	70
Emotional factors	0.950	0.938	<0.001	75.61

significant at the 0.01 level

Table 5 shows the positive and significant variables regarding gender. When analyzing the impact that gender has on emotions and utilitarian factors, we can conclude that only contentment (EM1), peace (EM2), relief (EM3), and the healthcare service matches my values and beliefs (EV2) present significant differences between gender. The results indicate that there are significant differences between men and women. These differences are only significant with the emotional variables, not the utilitarian variables (that is why only variables related to emotional factors are presented). The data indicate that, on average, women value more positive emotions such as contentment, peacefulness, relieved and that the healthcare center is in accordance with their beliefs and values. In all significant variables, women rate it better than men (see, contentment, women rate it with a score of 3.40/5 while men rate it with a 3.22; peaceful is rated by women with a 3.54/5 versus men who have rated it with a 3.32/5. The same happens with the variables of relevance and values that women are more satisfied than men (3.40/ vs. 3.29 and 3.57/5 vs. 3.29, respectively).

These data can be explained by the fact that emotions play a different role between gender. The data indicate that women value emotions more than men; thus, it could be concluded that men value the service itself, and women value how they feel it is developed. Thus, gender does not significantly impact the utilitarian factors (H1b is rejected); however, it does present significance on some of the emotional factors presented; therefore, H2b is accepted.

Table 5 – Means, SDs, and ranges for the measures. Mann-Whitney U and significance among measures and gender.

Measures	**Men (n=130) Mean ± SD**	**Woman (n=256) Mean ± SD**	**Mann-Whitney U**	**Significance**
EM1	3.22±0.90	3.40±0.92	14335	0.004**
EM2	3.32±0.99	3.54±0.90	14584	0.037*
EM3	3.29±1.24	3.40±1.25	13524	0.030*
EV2	3.29±0.98	3.57±0.99	14178	0.032*

**significant at the 0.01 level *Significant at the 0.05 level

Table 6 encompasses the results (positively significant scores) of the tested measures for the Mann-Whitney test regarding the values of mean and standard deviation. It is remarkable that, in the case of emotions and utilitarian factors, all measures were significant concerning the type of service, which may indicate a difference in the assessment made by patients. Thus, H1a and H2a are accepted as the results show that the type of services offered by the healthcare center impacts significantly and directly on the customer perception of utilitarian and emotional factors in the patient experience.

Table 6 – Means, SDs, and ranges for the measures. Mann-Whitney U and significance among measures and type of service.

Measures	Public (n=199) Mean ± SD	Private (n=187) Mean ± SD	Mann-Whitney U	Significance
EM1	3.17±0.93	3.53±0.86	14478	<0.001***
EM2	3.07±1.00	3.51±0.94	13805	<0.001***
EM3	3.34±0.98	3.71±0.90	14565	<0.001***
EM4	3.30±0.98	3.68±0.89	14472	<0.001***
EM5	3.26±1.00	3.58±0.95	15184	0.001***
EM6	3.04±1.06	3.50±0.92	13977	<0.001***
EM7	3.27±1.05	3.67±0.94	14706	<0.001***
EM8	3.31±1.13	3.56±1.02	16170	0.002**
EV1	3.10±1.34	3.62±1.08	14315	<0.001***
EV2	3.25±1.06	3.71±0.87	13938	<0.001***
EV3	3.16±0.99	3.68±0.86	13675	<0.001***
EV4	3.35±0.97	3.73±0.82	14525	<0.001***
PE1	3,55±0.94	3.51±0.81	13792	<0.001***
PE2	2,729±0.9	3.20±1.04	14166	<0.001***
PE3	3,04±1.02	3.60±0.88	12569	<0.001***
PE4	2,59±1.03	3.36±0.92	11003	<0.001***
PE5	2,87±1.02	3.62±0.85	11260	<0.001***
PE6	3,17±1.04	3.88± 0.89	12684	<0.001***
PE7	3,10±1.05	4.00±0.90	13346	<0.001***
SP1	3,46±1.00	4.00±0.85	14249	<0.001***
SP2	3,60±1.02	3.23±1.15	14551	<0.001***
SP3	3,07±1.02	3.73±0.94	14054	<0.001***
BI1	2,92±1.25	3.83±0.96	15925	0.015*
BI2	3,48±1.01	3.50±0.98	16019	0.017*
BI3	3,47±1.01	3.82±0.87	14782	0.001***
BI4	3,24±1.05	3.68±0.93	15892	0.015*
BI5	3,55±0.97	3.47±0.95	14593	<0.001***
BI6	3,44±1.03	3.26±0.98	13870	<0.001***

significant at the <0.001level ;significant at the <0.01 level *Significant at the <0.05 level

The Spearman's coefficients between the variables in each dimension were also calculated. Spearman's correlation coefficient is a nonparametric estimator applicable in the case of ordinal variables that do not necessarily meet normality criteria or whose scatter diagram does not show a linear functional relationship between variables such as those studied in this article. The coefficients in the utilitarian dimension estimate three variables related significantly ($p < 0.01$). The adaptation of the service to the patient needs and preferences and the flexibility and suitability of the healthcare service (rho=0.647). On the other hand, it is also positively related to the staff behavior and the physician's recommendations of care (rho=855). Besides the emotional dimension, the highest positive correlated variables are the sense of relief and the feeling of optimism (rho=0.859), the sense of relief and the feeling of hope (rho=0.833), and finally, the hope feeling and the stimulation one (0.808), all of them at ($p < 0.01$). Due to the highest number of variables in the study, the mean, standard deviation, and Spearman's coefficients for all the variables are not shown.

Ordinal Logistic Regression

Ordinal logistic regression was performed to test the first and second hypotheses formulated. The results are presented in Table 7. The link function was the logit link function because, in ordinal categorical dependent variable models, the responses have a natural ordering, and response probabilities depend on the individual predictors. This function aims to take a linear combination of the covariate values (which may take any value between ±∞) and convert those values to the probability scale, i.e., between 0 and 1 (MacKenzie et al., 2010). The independent variable in the test was experiential satisfaction. Table 7 shows the initial and regression models and the fit measures.

Table 7 – Ordinal logistic regression results for H_1 and H_2.

Dimension	**Initial Model**	**Regression model**	**Goodness-of-Fit**	**Likelihood Ratio; Chi-Square Test**	**Parallel Line Test**
		H_1			
Perceived quality of utilitarian values	PE1...PE7, SP1...SP6; BI1…BI6→ ES1	SP2(B = 0.698; p = 0.042*); BI1 (B =0.232; p = 0.005**); BI5 (B = 0.543; p = 0.05*); BI2 (B = 0.903; p = 0.000****); BI3 (B = 0.632; p = 0.001***)	([x^2 (658) = 640.313, p<0.682]; [x^2 (658) = 432.087, p<0.890])	440.205 (x^2 (16) = 279.637 ***)	H0 = 440,205 General 423,631 x^2 (16) = 16,575; p = 0.414
		H_2			
Emotional factors	EM1...EM8, EV1...EV4→ ES1	EM1(B = 0.543; p = 0.038**); EM6 (B = -0.168; p = 0.05*); EM8 (B = 0.346; p = 0.019*); EV2 (B = 0.631; p = 0.007**); EV4 (B = 0.979; p = 0.000***)	([x^2 (554) = 538.089, p<0.678]; [x^2 (554) = 361.942, p<0.900])	385.465 (x^2 (12) = 293.424 ***)	H0 = 385,465 General 377,117 x^2 (12) = 8,347; p = 0.757

In the Table: In the table * p < 0.05; ** p < 0.01 *** p < 0.000****; Goodness-of-fit = Pearson Chi-square test; Devian Chi-square test;

Regarding the first hypothesis, "The perceived quality of utilitarian factors is positively related to experiential satisfaction," the ordinal regression shows that the four variables studied have a significant and direct effect on customer satisfaction. Thus, the practices that have a more significant impact on customer perception when analyzing the quality of utilitarian values are those related to the staff behavior (SP2); access to unique treatments or discounts (BI1); involvement in the care process with complete and precise information (BI5); and level of trust in the care service (BI3) as they behave as predictors of the experiential satisfaction (ES1). This variable was considered in an ordinal scale and described increasing satisfaction states (satisfaction, more than satisfaction and delight). By interpreting the regression coefficients, for every unit increase of the independent variables SP2, BI1, BI5, and BI3, there was a predicted increase (0.698, 0.232, 0.543, and 0.903, respectively) in the odds of healthcare experiential satisfaction being in a higher (as opposed to lower)

category (ES1). Overall, the first hypothesis can be accepted as some of the independent variables analyzed to positively and significantly impact customer satisfaction.
Hypothesis 2 studies whether "the perceived emotions are positively related to experiential satisfaction." The results indicate that customers present higher satisfaction levels when emotional factors are involved; thus, healthcare services are also scored higher. Those emotional factors that are significant and positively related to higher levels of satisfaction are those related to patient's contentment (EM1), sense of cheerfulness (EM8), and the healthcare service that matches my values and beliefs (EV2), and reasonable awaiting time (EV4). Nevertheless, the stimulation (EM6) coefficient was negative, which means that for every unit increase of the independent variables EM6, there was a predicted decrease (0.168), respectively, in the odds of healthcare experiential satisfaction being a lower (as opposed to higher) category (ES1).

Focusing on the other results presented, the model fitting information stated a significant difference between the model established with and without the independent variables, in other words, and the existing relationship between the dependent and independent variables. The goodness-of-fitness results of the model were studied. Based on Pearson's chi-square and deviation statistics, the model–data fit is evaluated using the difference between the observed and the expected values. The results indicate that as both significances are greater than $p > 0.05$, H0 is supported, and the model fits the data Caputo et al., (2020). On the other hand, the assumption of parallelism indicates that all the models tested were fulfilled. The tested chi-square and their significance were higher than 0.05 ($p > 0.05$). In other words, this result indicates that the H2 is supported.

DISCUSSION AND CONCLUSIONS

This research is the first study to consider perceived emotions in the customer experience in the healthcare sector. Our results confirm that the two dimensions of patient experience significantly impacted patient experiential satisfaction. The KMO measures and the Alpha coefficient also establish the relevance of the variables considered in the healthcare sector. In addition, the analysis considers demographic variables such as gender and type of healthcare service. The model supports the proposed hypothesis and proves that utilitarian and emotional factors positively influence customer experience evaluation.

Focusing on the first hypothesis, which focuses on analyzing whether the quality utilitarian factors are related to patient satisfaction, the results indicate that a healthcare service that scored higher regarding the physician recommendations of care and medication gives access to the patients to unique treatments or discounts, involving them in the care process with complete and precise information and provide a higher level of trust were more likely to exhibit a greater experiential satisfaction. These results are supported by previous research by Bellio and Buccoliero (2020), pointing out that a perceived high-quality patient-doctor relationship and, in the case of the present study removing barriers and promoting the interaction patient-service positively affects the experiential patients' satisfaction. Surprisingly, gender does not significantly impact utilitarian factors, meaning that men and women have similar preferences according to the environment, staff-patient relationship, and the barriers and interactions with the healthcare service.

Regarding the second hypothesis, the analyses of the impact of emotional factors related to patient satisfaction, the results are aligned with Hussain et al. (2015). They indicate the importance of emotional care and transparency in patient care. Besides, the strategy of healthcare services should lay on emotional factors as much as the utilitarian ones. The health care services need to encourage their physicians and auxiliary staff to support the patient beyond medical treatment.

Furthermore, the study emphasizes the need to study gender preferences in the healthcare sector. In this sense, the impact of the demographic's variables and especially gender in the experiential satisfaction assessment of the patients have been studied. To date, the studies indicated that no significant differences were indicating that men and women made a different evaluation (experiential satisfaction) of the experience of receiving similar stimulus and care (Delanois et al., 2018), even when is recognized that some factors like pain management in means influenced most overall hospital rating while for women, staff responsiveness was the most critical variable, followed by communication with nurses, and doctors (Delanois et al., 2018). Other authors like Thompson et al. (2016) pointed out that patients' self-reports indicated gender differences in health care-seeking behavior, with women reporting they visited their primary care provider to a greater extent than men. However, the results of the Mann-Whitney test in the case of the present study suggest that there are significant differences. Aligned with the abovementioned, results indicate that emotional factors, such as contentment, peace, relief, and the healthcare service, match my values and beliefs and are considered differently depending on the gender. What is to say that women consider some emotions (such as those mentioned above) necessary in their patient experience and essential to achieve satisfaction. Analyzing this question in depth, through the contingency tables, the data suggest that women give more relevance to the significant emotional factors in the study than men in evaluating satisfaction. More profound and more extensive research is needed to reveal the origin of the differences.

On the other hand, the study of differences by type of health service revealed significant differences in all the variables evaluated for both utilitarian and emotional factors. The subsequent analysis of the contingency tables of the individual relationships between variables suggests that the emotional variables are better valued and higher. Results support previous studies developed by other authors as Mutiarasari (2021), concluding that the level of satisfaction of patients who sought treatment at private hospitals was higher than at public hospitals.

The implications for the healthcare services of the study lie in understanding the patient experience, gaining insights into their emotions, and managing the factors that influence their experiential satisfaction. Besides, exceptional and particular values and emotions influenced the evaluation of the service. Otherwise, the study's main limitation is its focus on a single region, although the results are well fitted according to the parameters of the applied analysis. Therefore, the results should be interpreted with caution and adapted to different contexts. Also, more empirical validation is needed. Future research should also consider other factors to confirm the relationship between the dependent and independent variables, explore and compare private and public services, and study gender influence on results.

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REFERENCES

Arnold, M. J., Reynolds, K. E., Ponder, N. and Lueg, J. E. (2005), "Customer delight in a retail context: investigating delightful and terrible shopping experiences", Journal of business research, Vol. 58 No. 8, pp. 1132-1145.

Bellio, E. and Buccoliero, L. (2021), "Main factors affecting perceived quality in healthcare: a patient perspective approach" The TQM Journal, Vol. 33 No. 7, pp. 176-192.

Berry, L. L., Carbone, L. P. and Haeckel, S. H. (2002), "Managing the total customer experience", MIT Sloan management review, Vol. 43 No. 3, pp. 85-89.

Bozpolat, E. (2016), "An Investigation of the Variables Predicting Faculty of Education Students' Speaking Anxiety through Ordinal Logistic Regression Analysis," Journal of Education and Learning, Vol. 6 No. 1, pp. 27-40.

Bueno, E. V., Weber, T. B. B., Bomfim, E. L. and Kato, H. T. (2019), "Measuring customer experience in service: A systematic review", The Service Industries Journal, Vol. 39, No. 11-12, pp. 779-798.

Caputo, F., Scuotto, V., Papa, A., and Del Giudice, M. (2020), "From Sustainability coercion to Social Engagement: The turning role of Corporate Social Responsibility", Corporate governance and research & development studies, Vol. 2, pp. 16-31.

de Vasconcelos, A. M., Barichello, R., Lezana, Á., Forcellini, F. A., Ferreira, M. G. G., & Miguel, P. A. C. (2015). Conceptualisation of the service experience by means of a literature review. Benchmarking: An International Journal.

Delanois, R. E., Gwam, C. U., Mistry, J. B., Chughtai, M., Khlopas, A., Yakubek, G. and Mont, M. A. (2018), "Does gender influence how patients rate their patient experience after total hip arthroplasty? ", Hip International, Vol. 28 No. 1, pp. 40-43.

Deshwal, P. (2016), "Customer experience quality and demographic variables (age, gender, education level, and family income) in retail stores", International Journal of Retail & Distribution Management, Vol. 44 No. 9, pp. 940-955.

Gilmore, J. H. and Pine, B. J. (2002), "Customer experience places: the new offering frontier", Strategy & Leadership, Vol. 30 No. 4, pp. 4-11.

Gummerus, J., von Koskull, C. and Kowalkowski, C. (2017), "Guest editorial: relationship marketing–past, present and future", Journal of services marketing, Vol. 31 No. 1, pp. 1-5.

Hair, J. F. Jr., Black, W. C., Babin, B. J., Aderson, R. E. & Tatham, R. L. (2009), Análise Multivariada de dados, ARTMED Editora, S.A, São Paulo, Brazil.

Hussain, J. A., Flemming, K., Murtagh, F. E. and Johnson, M. J. (2015), "Patient and health care professional decision-making to commence and withdraw from renal dialysis: a systematic review of qualitative research", Clinical Journal of the American Society of Nephrology, Vol. 10 No. 7, pp. 1201-1215.

Jain, R. and Bagdare, S. (2009), "Determinants of customer experience in new format retail stores", Journal of Marketing & Communication, Vol. 5 No. 2, pp. 34-45.

Jain, R., Aagja, J. and Bagdare, S. (2017), "Customer experience: A review and research agenda", Journal of Service Theory and Practice, Vol. 27 No. 3, pp. 642-662.

Jakson, I.L., Lawrence, S.M. and Abraham, E. (2017), "Patient satisfaction with health services in public and private Hospitals in South-South Nigeria", International Journal of Research in Pharmacy and Science, Vol. 7 No. 2, pp. 8 -15.

MacKenzie, D.I., Nichols, J.D., Royle, J.A., Pollock, K.H., Bailey, L. and Hines, J.E. (2010), Occupancy Estimation and Modelling: Inferring Patterns and Dynamics of Species Occurrence, Elsevier: London, UK.

Manresa, A. and Escobar Rivera, D. (2021), "Excellence in Sustainable Management in a Changing Environment", Sustainability, Vol. 13, pp. 2296.

Meyer, C. and Schwager, A. (2007), "Understanding customer experience", Harvard business review, Vol. 85 No. 2, pp. 1-11.

Mok, W. H., Tsarenko, Y. and Gabbott, M. (2008), "A measurement of emotional intelligence in service encounters", Australasian marketing journal, Vol. 16 No. 1, pp. 20-29.

Mutiarasari, D., Demak, I. P. K., Bangkele, E. Y., Nur, R. and Setyawati, T. (2021), Patient satisfaction: Public vs. private hospital in Central Sulawesi, Indonesia, Gaceta Sanitaria, Vol. 35, pp. S186-S190.

Osborne, W.J. (2015), Best Practices for Logistic Regression; SAGE: Newcastle Upon Tyne, UK.

Ozcelik, A. B. and Burnaz, S. (2019), "Customer experience quality dimensions in health care: perspectives of industry experts", Journal of Management Marketing and Logistics, Vol. 6 No. 2, pp. 62-72.

Palmer, A. (2010), "Customer experience management: a critical review of an emerging idea", Journal of Services Marketing, Vol. 24 No. 3, pp. 196-208.

Parasuraman, A., Zeithaml, V.A. and Berry, L.L. (1985), "A conceptual model of service quality and its implications for future research", Journal of Marketing, Vol. 49 No. 4, pp. 41-50.

Pérez-Cantó, V., Maciá-Soler, L. and González-Chordá, V. M. (2019), "User satisfaction in the Spanish health system: trend analysis", Revista de saúde publica, Vol. 53, pp. 53-87.

Pestana, M. H. and Gageiro, J. N. (2008), Análise de dados para ciências sociais – a complementaridade do SPSS, Edições Sílabo, Lisboa, Lda.

Plutchik, R. (1980), A general psychoevolutionary theory of emotion. In Theories of emotion. Academic Press, New York, NY.

Pullicino, G., Sciortino, P., Calleja, N., Schäfer, W., Boerma, W. and Groenewegen, P. (2015), "Comparison of patients' experiences in public and private primary care clinics in Malta", The European Journal of Public Health, Vol. 25 No. 3, pp. 399-401.

Shen, L. and Dillard, J. P. (2007), "The influence of behavioral inhibition/approach systems and message framing on the processing of persuasive health messages", Communication Research, Vol. 34 No. 4, pp. 433-467.

Steine, S., Finset, A. and Laerum, E. (2001), "A new, brief questionnaire (PEQ) developed in primary health care for measuring patients' experience of interaction, emotion and consultation outcome", Family practice, Vol. 18 No. 4, pp. 410-418.

Thompson, A. E., Anisimowicz, Y., Miedema, B., Hogg, W., Wodchis, W. P. and Aubrey-Bassler, K. (2016), "The influence of gender and other patient characteristics on health care-seeking behaviour: a QUALICOPC study", BMC family practice, Vol. 17 No. 1, pp. 1-7.

Verhoef, P. C., Lemon, K. N., Parasuraman, A., Roggeveen, A., Tsiros, M. and Schlesinger, L. A. (2009), "Customer experience creation: Determinants, dynamics and management strategies", Journal of Retailing, Vol. 85 No. 1, pp. 31-41.

Westbrook, R. A. and Oliver, R. L. (1991), "The dimensionality of consumption emotion patterns and consumer satisfaction", Journal of consumer research, Vol. 18 No. 1, pp. 84-9.

Wilson, E.V. and Strong, D.M. (2014), "Editors' introduction to the special section on patient-centered-health: research opportunities and challenges", Communications of the Association for Information System, Vol. 34, pp. 323-336.

Worlu, R., Kehinde, O. J. and Borishade, T. T. (2016), "Effective customer experience management in healthcare sector of Nigeria: a conceptual model", International Journal of Pharmaceutical and Healthcare Marketing, Vol. 10 No. 4, pp. 49-466.

Zhang, Y., Feick, L. and Price, L.J. (2006), "The impact of self-construal on aesthetic preference for angular versus rounded shapes", Personality and Social Psychology Bulletin, Vol. 32 No. 6, pp. 794-805.

Development of scenario-based methods for testing the quality of chemical protective gloves regarding ergonomic requirements

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ABSTRACT

Purpose – The purpose of this paper is to fill the lack of a roadmap for examination of ergonomic quality of chemical protective gloves in standards and research by defining a new set of customer requirements and product specifications. In addition, the authors aim to develop scenario-based test methods that can be used to evaluate these specifications.

Design/methodology/approach - A literature review is conducted to identify a response scenario for a chemical, biological, radiological and nuclear (CBRN) incident that emergency services should undertake. Based on this scenario and its related activities, the deployment of protective clothes could be represented as a process, which contributes to the definition of ergonomic customer requirements through a survey with experts from the fire department. For each requirement, an empirical, comparable test procedure is developed, which considers the practical application in emergency missions and is directly related to the tasks listed in the identified scenario.

Findings – This research presents new product specifications in different areas of ergonomics, which can be evaluated by the developed scenario-based test methods.

Research limitations - The number of fire departments surveyed may be expanded, leading to the identification of additional requirements.

Practical implications- The results in this research are a unique study that can be used to evaluate the ergonomic quality of chemical protective gloves by manufacturers to improve customer satisfaction by reducing the physical burdens of the gloves.

Originality/value - The research contributes to more attention to the ergonomic specifications of protective gloves, which otherwise tend to take a back seat.

Keywords: Chemical protective gloves, Ergonomics, Quality, Customer requirements

Paper type: Research paper

INTRODUTION

The usage of chemical protective clothing (CPC) is essential in the event of possible contact with chemical, biological, radiological and nuclear (CBRN) substances in the industry, military or fire department. The CPC wearers are exposed to a very high level of physical and psychological stress, which is composed of several factors, such as the increasing humidity and temperature inside the suits due to their impermeability (Havenith, et al., 2011). The chemical protective gloves as part of the CPC are no exception in this regard.

In practice, the focus is placed on the protective effect of chemical protective gloves, with the result that ergonomic requirements are pushed into the background. This is accompanied by a reduction in the range of possible actions during use, which can even jeopardize the success of a mission. With the exception of the few requirements on ISO 21420:2020, there are no specifications for ergonomic requirements, so that it is not possible for the manufacturers to objectively determine the ergonomic quality of the produced chemical protective gloves in a regulated manner (Barker, 2005). ISO 21420:2020, which replaced EN 420:2003 + A1:2009, lists some general requirements for the protective gloves, such as cleanability, size and breathability of gloves. In this standard, a method for evaluating the finger dexterity of the gloves is presented, but a task-related test method for evaluating other important characteristics of the gloves, such as the tactility or gross motor skill, is missing (ISO, 2020).

In the literature there are some methods for testing fine and gross motor skills of the protective gloves. The O`Connor Finger Dexterity Test, one of the most commonly used methods for testing fine motor skills, involves the subject inserting pins into a pegboard (Hines & O'Connor, 1926). Another common method is the Minnesota Two-Handed Turning Test, which tests gross motor skills by retrieving 60 cylindrical blocks from their holes and turning them over with one hand and inserting them into other holes with the other hand (Betts, 1946). However, these test methods do not directly relate to the tools to be used by responders in their operations. Therefore, the realism and practical orientation of these methods is lacking. Nelson and Mital tested the tactility of surgical gloves by asking subjects to blindly detect changes in the roughness of sand papers of different thicknesses and pipes of different diameters (Nelson & Mital, 1995). Nonetheless, this test method is limited to assessing the ability to detect changes in the shape of the objects and does not evaluate the ability to work with the objects while wearing the gloves. Krausman and Nussbaum evaluated the effect of chemical protective clothing on the use of wearable input devices, asking participants to enter sixteen text input strings using both a wearable mouse and a touchpad (Krausman & Nussbaum, 2005). In a similar work, Allan tested military aviation chemical biological protective gloves by requiring subjects to type a lengthy sentence. He also developed a mission-relevant test method that required test participants to manipulate 20 cockpit controls (Allan, 2007). Ramadan evaluated the effects of wearing different gloves, including chemical protective gloves, on grip strength using a hand dynamometer (Ramadan, 2017). While the aforementioned work tested the tactility and dexterity of the gloves, other important specifications such as gloves donning and doffing time were not considered.

This work presents a number of ergonomic requirements defined by the analysis of the different hazardous area response scenarios and in various discussions with experts from fire departments in Germany within the framework of the AgiCSA project at the University of Wuppertal (BMBF, 2020). In addition, a job-related test method is developed for each ergonomic requirement to evaluate the ergonomic quality of chemical protective gloves in a practical way.

RESEARCH METHODOLOGY

In order to define a comprehensive list of ergonomic requirements and task-related test methods, it is necessary to observe a CBRN response scenario, which should be carried out by operation squad in case of an incident. For this purpose, this paper first considers a scenario, based on a literature review of a national and an international guideline and set of rules (FwDV 500 and NATO-CEPC, respectively). This results in a set of activities that a member of the operation squad must perform, which leads to the representation of the CPC deployment as a process. Accordingly, the necessary ergonomic specifications of the chemical protective gloves are defined by an interview with experts from fire departments in Germany. A test method is developed for each specification, that is directly related to the listed activities and tasks in the identified scenario. Finally, to prove the suitability of the test methods, they are applied to the chemical protective gloves from the manufacturer uvex Winter Holding GmbH & Co. KG and also to innovative chemical protective gloves developed in the AgiCSA project at the University of Wuppertal. The subsequent statistical evaluation of the test results allows an initial assessment of the existing deficiencies and problems of the "AgiCSA" gauntlet glove, which can be used as a basis for improving the quality of ergonomic features of the gloves.

LITERATURE REVIEW

FwDV 500

Nationally unified fire service regulations (in German: FwDV) are established to regulate the activities of fire departments in Germany in the form of guidelines and instructions. These are drawn up by a project group of board of firefighting affairs, catastrophe protection and civil protection (in German: AFKzV), with the aim of establishing the necessary uniformity in the fire department in all

German federal states. The "Fire Service Regulation 500 (FwDV 500)" defines tactical rules to be observed during operations involving CBRN hazards. According to the FwDV 500, the operation squad assumes the tasks of *"1- sealing, 2- collecting, 3- extinguishing, 4- technical assistance"*. In addition, this document describes the detailed activities to be performed during a CBRN deployment (FwDV 500, 2012).

NATO's CEPC Response Guidelines

The Civil Emergency Planning Committee (CEPC) is NATO's senior advisory body and serves to protect civilians and deploy civilian resources in support of NATO's objectives. CEPC provides NATO in several areas such as counterterrorism and consequence management, humanitarian assistance and disaster response, and critical infrastructure protection. The CEPC published the Response Guidelines document as part of "The Non-Binding Guidelines and Minimum Standards for CBRN First Responders (NBG/MS)" package to assist first responders in planning and executing responses to a CBRN incident scenario. This guideline describes the tasks required to conduct an effective response and outlines the capabilities and equipment. These activities are divided into four steps: *"1- Information gathering, assessment and dissemination, 2- Scene management, 3- Saving and protecting life, 4- Additional/specialist support"*. The detailed activities in each step are described in this guide (CEPC, 2014).

RESULTS

Process of CPC Deployment

Thanks to the information and the CBRN scenario related activities found in the aforementioned guidelines, the CPC deployment can be represented as a process. In addition, the individual process sections are worked out and explained accordingly. Depending on the actual equipment and tactics of the particular fire department, other variations of the process presented here may arise. As shown schematically in Figure 1, this process consists of 3 rough steps: Dressing up, Use in the hazardous area and Decontamination.

In the first process step, i.e. Dressing up, the CPC deployment begins. At the command of the superior executive the squad member begins to assemble the necessary equipment (clothes, gloves, masks, etc.). In the hazardous area different activities are possible, which are performed with the equipment mentioned. The individual sub-processes have no fixed sequence and can be restarted again and again. Once the operation in the hazardous area is completed, the squad member leaves it for the decontamination station. Due to the limited supply of breathing air, the deployment time is limited to

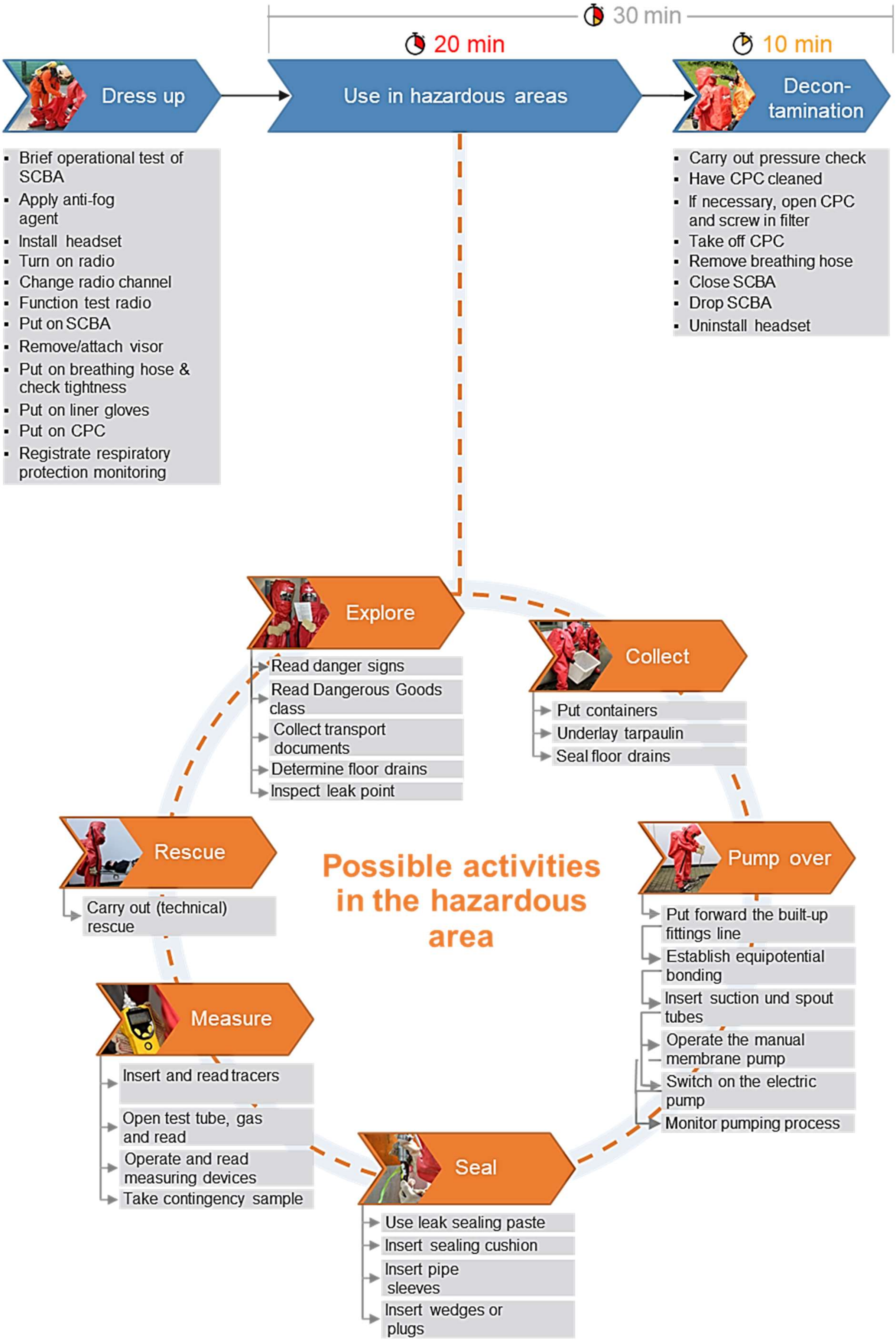

Figure 1 - Schematic representation of the CPC deployment process

30 minutes, 20 minutes of which are being used for the deployment in the hazardous area and the remaining ten minutes to be used for the subsequent decontamination. The detailed activities, that the operation squad performs with the CPC are listed in the Figure 1 for each process and sub-process. These form the basis for defining the requirements, which are determined in the following part of this paper in a survey with experts from fire department.

Customer Requirements and Product Specifications

A digital customer requirement workshop concept was developed at the University of Wuppertal to capture the requirements, desires and needs of responders in CBRN situations with respect to the illustrated CPC deployment processes shown in Figure 1. Until December 2020, eight digital workshops were held with 40 firefighters and also students from the Safety Engineering and Quality Engineering programs at the University of Wuppertal. Based on Design Thinking, the workshops consisted of two phases: the problem analysis phase and the solution phase. In the first phase, the participants first worked out their own needs and requirements for various pieces of CPC equipment, including chemical protective gloves, based on the identified scenario and the listed activities in the CPC deployment process. These were supplemented by findings from market research provided by the authors of this paper. From this, the participants identified the most important requirements and combined them into a "point of view". In the second section, the participants developed solution ideas and an initial sketched prototype from the "point of view" they had developed. However, these solutions and ideas are not the subject of this paper.

Of all the requirements identified in these workshops, 17 relate to chemical protective gloves, of which 11 requirements directly concern the ergonomic aspects of the gloves. For each requirement a product specification is defined, which needs to be tested with a proper method to evaluate the ergonomic quality of the gloves. In addition, the existence of these requirements in a relevant standard is researched. The results are listed in Table 1. From this table it can be seen that only three requirements identified by the customers in the workshops are already considered in the standards.

Table 1 – The ergonomic costumer requirements and the respective product specifications

ID	Requirement	Specification	Available Standard
1	The gloves must be able to be put on and taken off in a short time	Donning and Doffing	None
2	The gloves must allow for the highest possible fine motor skills	Fine Motorics	None
3	The gloves must allow for the greatest possible gross motor activity	Gross Motorics	None
4	The gloves should be easy and intuitive to use	Usability	None
5	The grip strength should not be significantly negatively affected by the glove	Grip Strength	None

ID	Requirement	Specification	Available Standard
6	The sensoric and tactile ability with the hands must not be severely limited by the gloves	Tactility	None
7	The gloves must have an oval opening so that they can be put on	Opening	None
8	The gloves must be functional even in case of improper use, e.g. when they are put on incorrectly due to mental stress or haste	Functionality at Fault	None
9	The ergonomic properties of the gloves must not vary greatly after cleaning the gloves	Cleanability	ISO 21420
10	Sweating of the hands of the wearer must not greatly affect the ergonomic properties of the gloves	Breathability	ISO 21420
11	The gloves must be adjusted for different hand sizes so that they fit properly	Size	ISO 21420

In the final step, the results of the eight customer requirements workshops are linked and standardized in the context of model-based requirements management. To this end, the ReMaiN approach (Schlueter, 2020), which is suitable for cross-disciplinary product developments, is used. By using a uniform, standardized metamodel, it is possible to map requirements in a standardized way and make them available to the project partners. Based on the requirements list in Table 1, an initial model of the requirements (t_0 prototype) including their relations to the chemical protective gloves is created in the iQUAVIS software. This t_0 prototype is based on the rules of Demand Compliant Design (DeCoDe) (Schlueter, 2017), according to which, in addition to the requirements, the functions, components and the deployment process of the CPC are mapped together including the relations between them, which provides the project consortium with a uniform view of the product to be developed. Figure 2 shows a simple DeCoDe model, whereby it can be seen that the individual elements can be linked together. By extending such a model with additional requirements, components, processes, and functions, and by hierarchizing individual ones of these among themselves, a complex model is created. Such a model created for AgiCSA chemical protective gloves can be seen in Appendix A.

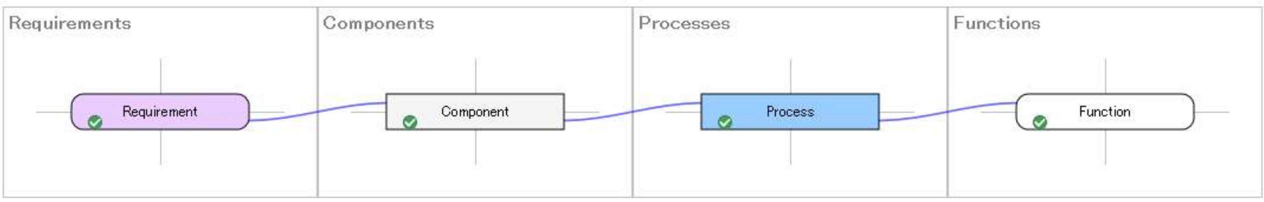

Figure 2 – Structure of a simple DeCoDe model (based on (Schlueter, 2017))

Scenario-based Test Methods

As shown in Table 1, only three customer requirements (i.e. Cleanability, Breathability and Size) identified in the workshops are mentioned in ISO 21420, whereas other requirements and specifications that are important from the customer's point of view are missing in this standard. For this reason, practical test methods are developed for these specifications in this work, which are designed in the form of a subjective evaluation of the gloves by test persons (e.g. firefighters) after performing the job-related test tasks. In addition, for some test tasks, the execution time is measured in order to achieve objective and therefore comparable test results. The advantage of these methods is that the test tasks and the devices to be used as test tools are those that are to be carried out in the CBRN incident scenario by the operation team with their chemical protective gloves. This enables a realistic evaluation of the ergonomic quality of the gloves. Table 2 shows the developed test methods for the specifications to be tested in this work with the listed necessary tools.

Table 2: The developed test methods

Test-ID	Specification	Tool	Task	Test criteria
1.1	Donning and Doffing	-	Measuring the time by putting on and taking off the gloves	subjective evaluation & Time
2.1	Fine Motorics I	Nuts and bolts	Attaching nuts on bolts with different diameters	subjective evaluation & Time
2.2	Fine Motorics II	Toggle Latches	Locking latches with different sizes	subjective evaluation & Time
2.3	Fine Motorics III	Buckles	Inserting the plug-in parts into buckles of different sizes	subjective evaluation & Time
2.4	Fine Motorics IV	Carabiners	Connecting carabiners with different sizes to chains	subjective evaluation & Time
3.1	Gross Motorics	Storz couplings	Connecting Storz couplings with different sizes	subjective evaluation & Time
4.1	Usability	-	Recording the number of mistakes during the execution of other test tasks	Yes/No
5.1	Grip Strength	Hand grip dynamometer	Holding the hand grip dynamometer as tight as possible with and without gloves	Ratio of gripping force with and without gloves

Test-ID	Specification	Tool	Task	Test criteria
6.1	Tactility	Nuts	Lifting nuts of different sizes from a smooth surface with one hand and placing them on the other hand	subjective evaluation & Time
7.1	Opening	-	Visual inspection while putting on the gloves	Yes/No
8.1	Functionality at Fault	-	Incorrect donning of gloves and performing a random test task	Time

Between the specifications in Table 2, the opening of the gloves can be tested by visual inspection while putting on the gloves. To evaluate the usability of the gloves, the number of mistakes during the execution of the test tasks can be noted.

The difference between the grip strength with and without glove can be determined with a hand dynamometer. The hand dynamometer of the company CAMRY (model no. EH101) is used for this measurement. The measuring device provides results in kg with an accuracy of ± 0.5 kg. A measurement is performed with the dominant hand consecutively three times each at an interval of two minutes, first without glove as a reference and then with glove. The test result is given in relative terms as the ratio of force transmission with and without the glove.

Four test methods are developed to test the fine motor skills of the chemical protective gloves, in which the subject has to perform different tasks with the tools used in the CBRN scenarios, for example toggle latches with different sizes, which are often used to secure objects against tipping over, such as fire extinguishers and gas cylinders, but also straps to fix tarpaulins, or metal rings to seal lids on barrels and crates. Storz couplings in three different sizes, which are used to connect fire hoses to one another, are also selected as a test tool for evaluating the gross motoric properties of the gloves.

The gloves must have the highest possible tactile sensitivity, especially for the operation of devices such as radio or measuring instruments, where the tactile sensitivity in the fingertips, especially in the index finger, is particularly necessary. The tactility of the gloves can be tested by lifting the nuts of five different sizes from a smooth surface with one hand and placing them on the other hand.

As discovered in the workshops, the functionality of the gloves in case of a fault can be important, if they are used improperly, e.g. if they are put on incorrectly due to psychological stress, especially by the emergency services with less experience. To simulate this, the subject can be asked to put the right glove over the left hand and the same way for the other hand. Then a test task can be performed and finally the difference between the test results (the execution time) from the two tests can be compared.

For the subjective evaluation of the specifications, a questionnaire should be prepared and made available to the test subjects. The test subject should rate the ergonomic quality of the gloves from 1 to 5 (1 being the worst and 5 being the best) after completing the corresponding test tasks. An evaluation of “X” is used in case of a failed test task and should be selected if the subject is unable to complete the test task due to the poor ergonomic quality of the gloves or the pain sensation (in accordance with ISO 21420, 2020). The examiner also measures the execution time of the test tasks and notes this and other test results in the test report.

VALIDATION

Test methods execution

In order to verify the suitability of the test methods presented in this work they are used to test the ergonomic quality of two chemical protective gloves, the rubiflex NB40S chemical protective gloves from the manufacturer uvex Winter Holding GmbH & Co. KG and the new innovative chemical protective gloves developed in Project AgiCSA. The most important product information for both gloves is listed in Table 3.

Table 3 - uvex rubiflex NB40S (uvex, 2022) and the AgiCSA chemical protective gloves

	Product Information	
	 **uvex rubiflex NB40S**	 **AgiCSA**
Material	Cotton interlock	Cotton interlock
Coating	Nitrile rubber (NBR special)	Nitrile rubber (NBR special)
Coating thickness	0.50 mm	0.47 mm
Glove length	40 cm	40 cm
Size	9 (L/XL)	9 (L/XL)
Version	with gauntlet	with gauntlet

As it can be seen in Table 3, the two test objects have many similar design features that allow a fair comparison. Nevertheless, many innovative methods - independent of the coating technology and layer thickness - have been implemented to improve the ergonomic properties of AgiCSA gloves, such as the type and formulation of the coating polymer, which can improve the haptics in addition to a robust and solid crosslinking density. It should be noted that the other geometric parameters, such as the thickness of the glove fingers and also the distance between them or the thumb and hand circumference vary between the uvex and AgiCSA gloves.

The test tasks listed in Table 2 were carried out over five days at the "Currenta fire department" in the city of Krefeld in Western Germany. 15 male members of the CBRN emergency team of the Currenta fire department were recruited as test subjects, all of whom already had experience with CPC. All subjects underwent the tests with each of the 2 gloves. There was also a break of at least 3 minutes between each test. Immediately before the tests began, the subjects were asked about their age, as well as their physiological situation (complaints in the spine, shoulders, elbows, wrists or fingers). In addition, the hand length as well as the hand circumference of the test subjects were measured based on the instructions in ISO 21420 (ISO, 2020). Table 4 shows the basic anthropometric information of the subjects.

Table 4 - Basic anthropometric data of the test subjects

Parameter	Average ± Standard deviation (x ± s)	Min	Max
Age	41 ± 12.10	23	60
Hand length (mm)	194 ± 8.06	180	215
Hand circumference (mm)	200.7 ± 10.327	170	210

To perform the test tasks the required tools as mentioned in Table 2 are fixed on a solid wooden board and used during the test, as shown in Figure 3. The tools on this board are grouped according to the test tasks and sorted by their size. They are also visually separated from each other and spaced far enough apart so that they are not affected by adjacent objects on the board. The test board was designed to rest flat on a table at three points to ensure an ergonomic posture for the subject.

Figure 3 - The test board with the mounted required test tools

Further on, the test results for the presented characteristics are statistically evaluated. In the test room, the temperature ranged from 21˚C to 25˚C and the relative humidity ranged from 40% to 48%. In order to remain in accordance with the ISO 21420, the specimens (i.e. gloves) were conditioned for at least 24 h at 25 °C and 45 % relative humidity prior to testing. The test process was started within 10 min after removal from conditioning (ISO, 2020). In the next section, the test results including the execution time and the subjective evaluation results for the two gloves are presented in relation to the specifications tested by the subjects.

Test results evaluation

In this experiment the donning and doffing comfort of the gloves is tested. Figure 4 shows that, according to the test subjects' opinion, the removal of the two gloves is uniformly comfortable. The time taken to remove the gloves is almost the same (difference only 0.34 s) on average. In addition, the donning time for the gloves is measured, which is also approximately the same (difference only 0.18 s) for both gloves, as shown in the diagram.

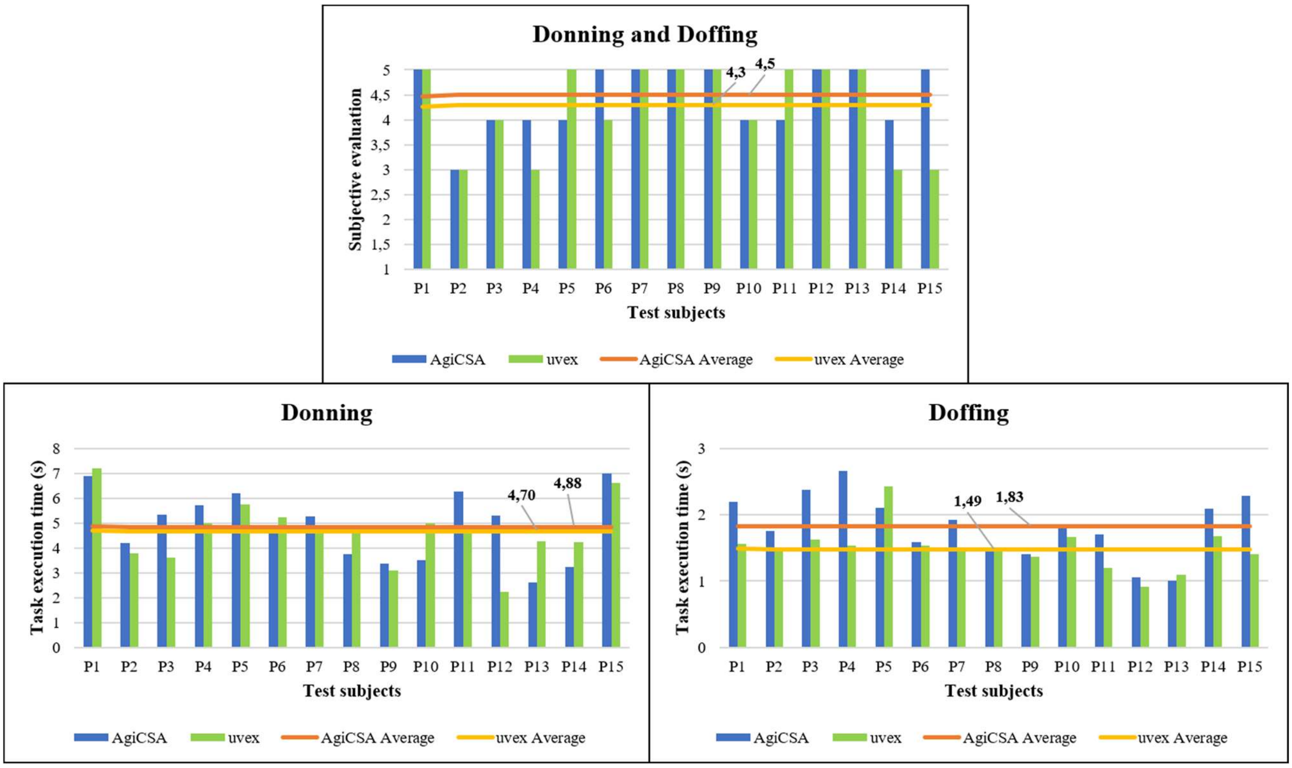

Figure 4 – Donning and Doffing (top: subjective evaluation / bottom left: donning time / bottom right: doffing time)

The AgiCSA gloves have better fine motoric ability than the uvex gloves, as shown in Figure 5, which explains the higher average subjective rating of these gloves. The task execution took longer on average (+0.89 s) for Fine Motorics IV with the uvex gloves, but longer (+18,76, +2.54 and +0.76 s, respectively) for Fine Motorics I, II and III with the AgiCSA gloves.

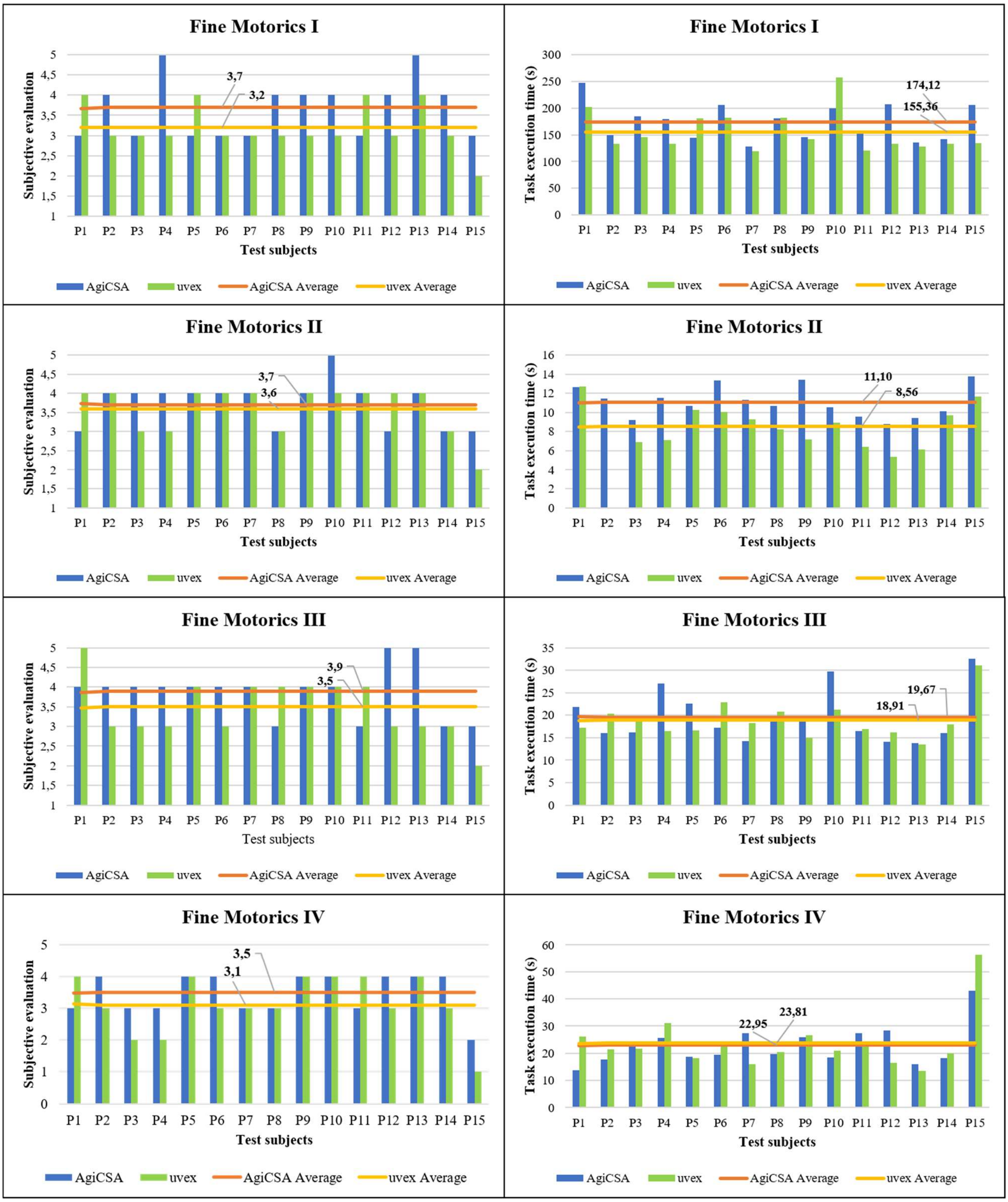

Figure 5 – Fine Motorics (left: subjective evaluation / right: time)

Figure 6 shows the same gross motor property of both gloves on average, the execution time for AgiCSA gloves is though on average 1.12 second longer than for uvex gloves.

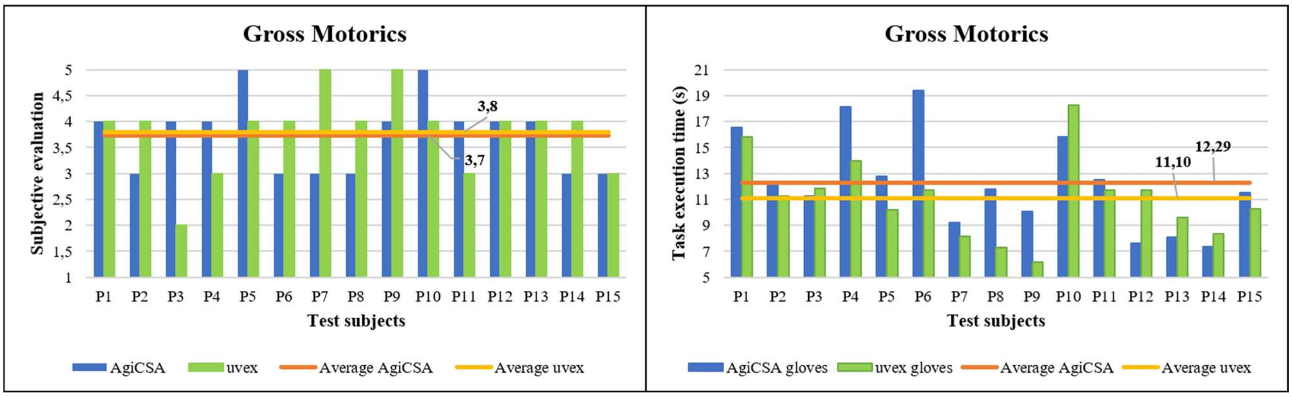

Figure 6 – Gross Motorics (left: subjective evaluation / right: time)

The grip strength for both gloves is measured as the difference between the gripping force with and without glove with the dominant hand of the test subjects. Figure 7 (right) shows that the difference in gripping force between the bare and the gloved hand is the same for both products. The same average subjective evaluation of both gloves (Figure 7 left) confirms this fact on the part of test subjects' opinion.

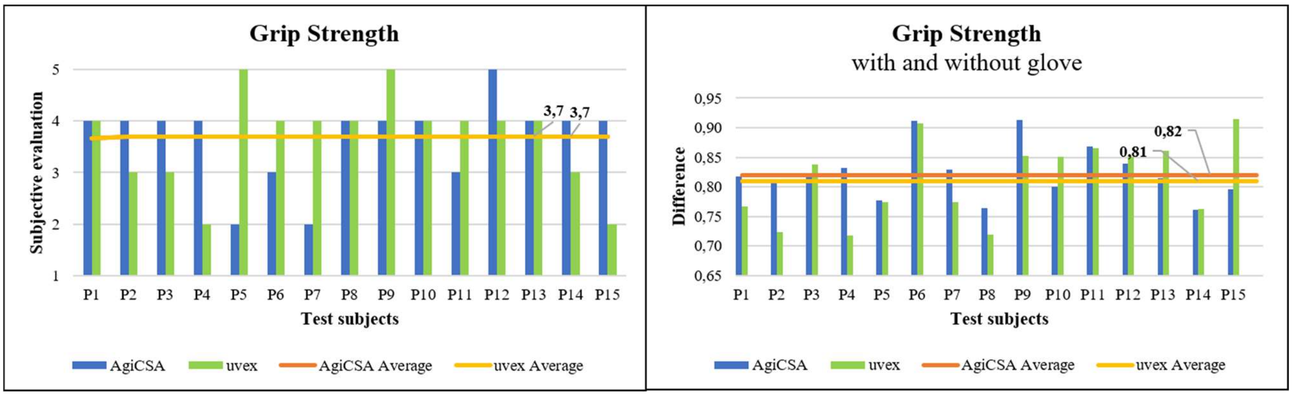

Figure 7 – Grip strength (left: subjective evaluation / right: difference between bare and gloved hand)

The tactility of the two gloves is approximately the same, although the average execution time for the task with AgiCSA gloves in this test was on average 1.42 second longer than with the uvex gloves, as shown in Figure 8.

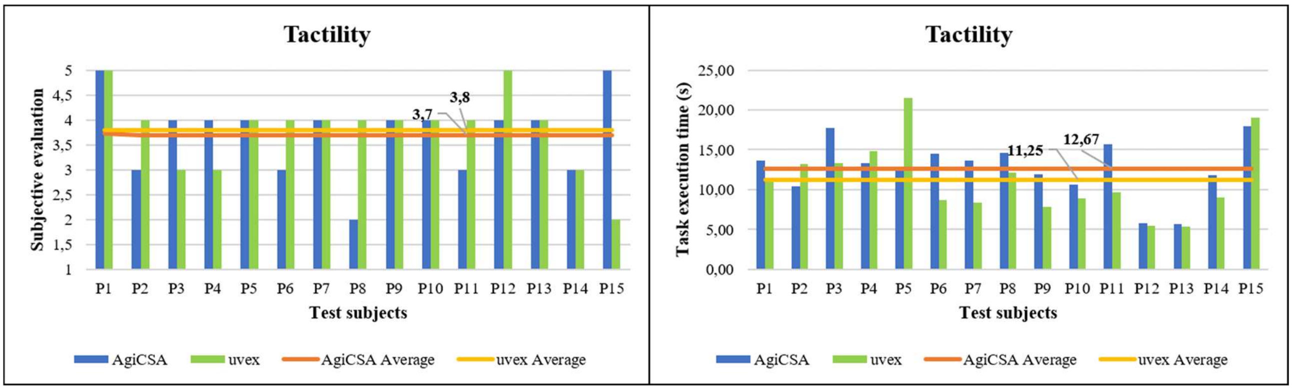

Figure 8 - Tactility (left: subjective evaluation / right: time)

Finally, the functionality of the gloves in the event of a fault case is determined by donning them incorrectly and performing the test task in Fine Motorics II and comparing the average task execution time between the two test conditions. The smaller the time difference is, the better the functionality of the glove is in the event of a Fault. As it can be seen in Figure 9 the test subjects needed on average even less time (-1.49 s) to perform the test task with the incorrect donned AgiCSA gloves. However, the task execution time is increased by an average of 1.52 seconds after the uvex gloves are put on incorrectly compared to the test results of the correct donning situation (See Fine Motorics II in Figure 5 right).

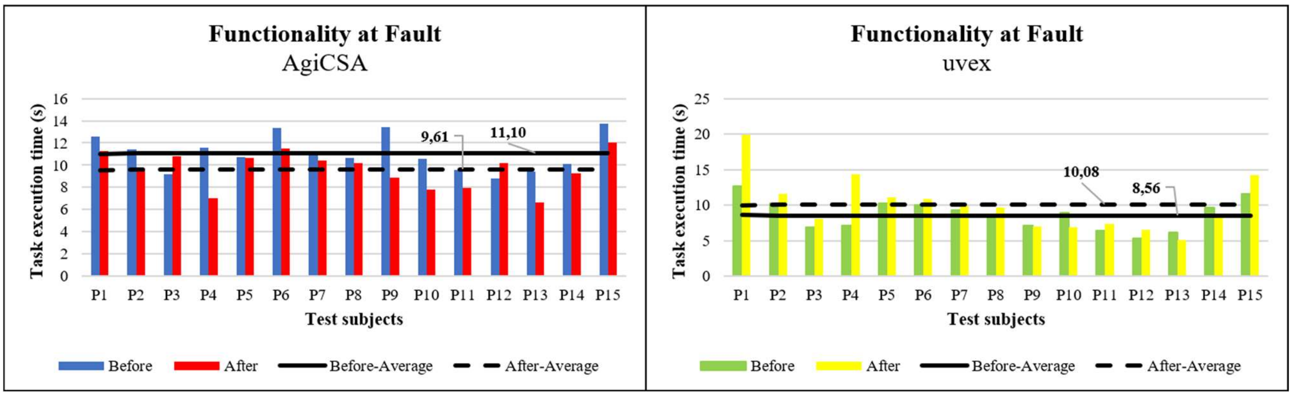

Figure 9 – Functionality at Fault (left: AgiCSA / right: uvex)

Moreover, to prove the importance of the defined specifications, the test subjects were asked about the importance of the specifications after each test. They weighted this importance from 1 to 5, with 5 representing the highest importance and 1 the lowest. Figure 10 confirms the high importance of the ergonomic specifications tested in this work according to the opinion and experience of the 15 test subjects.

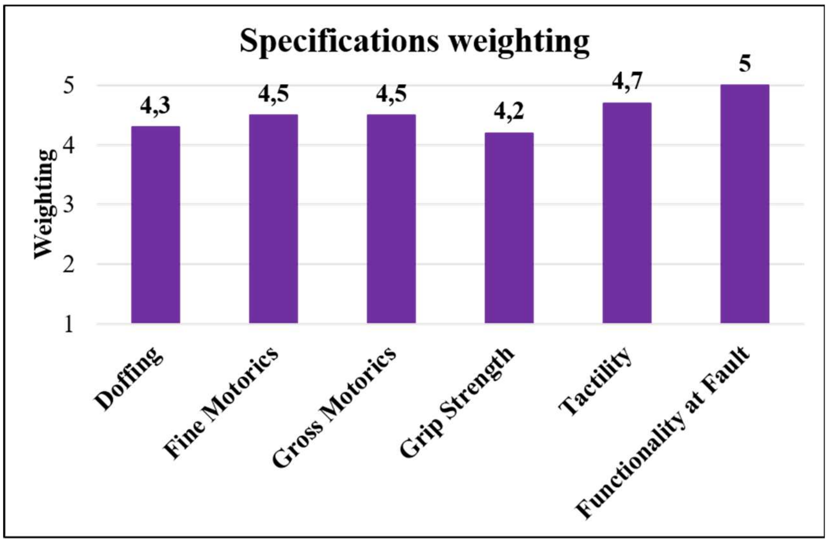

Figure 10 – Weighting the specifications (Mean value of 15 subjects' opinion)

The results of the statistical analysis of the ergonomic subjective evaluations of the tested gloves are presented in Table 5.

Table 5 – Statistical evaluation for AgiCSA and uvex gloves

	Subjective Rating of the gloves (X,1,2, … 5)																	
	AgiCSA									**uvex**								
	Mean	*Median*	*Mode*	*Variance*	*Standard dev.*	*Skewness*	*Kurtosis*	*Range*	*Coeff. of Variation*	*Mean*	*Median*	*Mode*	*Variance*	*Standard dev.*	*Skewness*	*Kurtosis*	*Range*	*Coeff. of Variation*
Donning and Doffing	4.5	5	5	0.40	0.64	-1.25	-0.01	2	0.14	4.3	5	5	0.78	0.89	-1.20	0.62	2	0.21
Fine Motorics I	3.7	4	3	0.52	0.72	-0.86	-0.04	2	0.20	3.2	3	3	0.31	0.56	1.23	2.46	2	0.17
Fine Motorics II	3.7	4	4	0.35	0.60	-0.16	0.42	2	0.15	3.6	4	4	0.40	0.63	0.50	1.44	2	0.17
Fine Motorics III	3.9	4	4	0.41	0.64	-0.27	0.70	2	0.16	3.5	3	3	0.55	0.74	-0.50	-0.23	3	0.21
Fine Motorics IV	3.5	4	4	0.41	0.63	-0.20	-0.07	2	0.18	3.1	3	3	0.84	0.91	-0.36	-0.01	3	0.29
Gross Motorics	3.7	4	4	0.49	0.70	-0.94	-0.01	2	0.19	3.8	4	4	0.60	0.77	0.01	1.00	3	0.20
Grip Strength	3.7	4	4	0.66	0.82	0.70	1.81	3	0.22	3.7	4	4	0.81	0.90	-0.28	1.10	3	0.24
Tactility	3.7	4	4	0.64	0.80	-0.47	0.67	3	0.21	3.8	4	4	0.60	0.77	0.02	1.00	3	0.20

It can be seen from Table 5 that the standard deviation (and/or variance) for the uvex protective gloves is greater than for the AgiCSA (with the exception of Fine Motorics I and Tactility), indicating that the AgiCSA glove is more universally applicable, while the uvex glove provides very good ergonomic performance for some individuals but is less applicable for some individuals. With the exception of Fine Motorics III and Grip Strength have the test results of uvex gloves also a significantly greater kurtosis, i.e. the values tend to have heavier tails or more outliers. Furthermore, unlike the uvex, all specifications of the AgiCSA glove except Grip Strength have test values of left-skewed distributions (skewness<0), meaning that values greater than the mean (i.e., the higher subjective evaluation scores) are observed more frequently by the subjects. This can be seen in Figure 11, which shows the frequency of the achieved subjective evaluation scores for the overall results of all performed tests. As illustrated in this diagram, the subjects chose the scores 4 and 5 more frequently for AgiCSA gloves than for the uvex gloves. The dashed line shows the total mean value of all test results for both gloves (3.8 and 3.6 for AgiCSA and uvex, respectively).

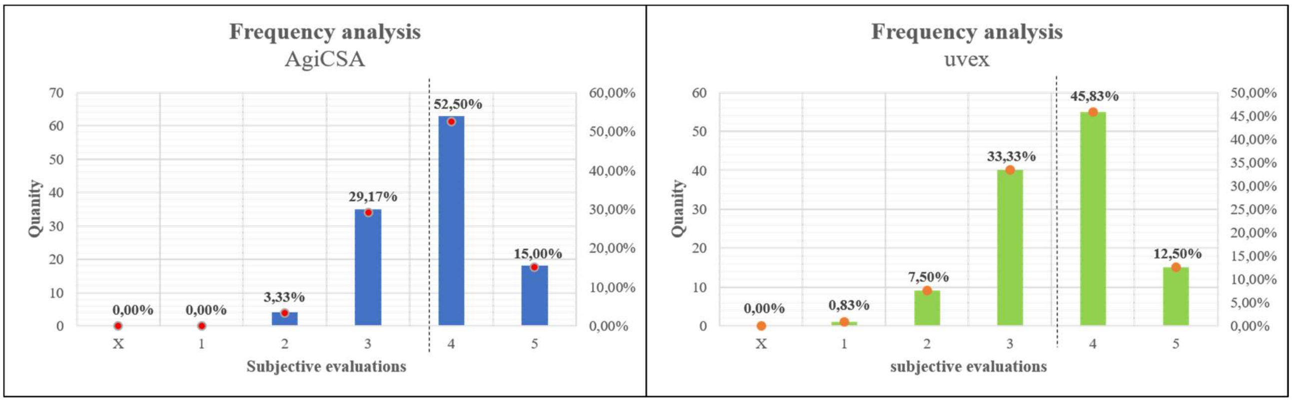

Figure 11 – Frequency of the selected evaluation scores by subjects

CONCLUSIONS

This paper has defined the different processes of CPC deployment based on the instruction in two different guidelines and regulations. Interviews with experts from the fire departments during the multi-day workshops, made it possible to identify their wishes and requirements regarding the ergonomics of the chemical protective gloves as a part of the CPC. The new product specifications resulting from these customer requirements can be divided into six ergonomic areas, namely Donning and Doffing, Fine Motorics, Gross Motorics, Grip Strength, Tactility and Functionality at Fault. These are linked together in the iQUAVIS software according to the rules of Demand Compliant Design (DeCoDe) in order to map them in a standardized way and make them available to the project partners.

For each of these specifications, scenario-based test methods were developed in which test subjects are asked to evaluate the ergonomic quality of the gloves after performing various tasks with different tools commonly used in the identified CPC deployment process. In addition, the execution time is to be measured by the examiner in order to increase the objectivity of the test results. The advantage of these methods lies in their realistic job-related test tasks, which are actually to be carried out by the operation squad in the CBRN incident scenario.

To prove the suitability of the developed test methods, they were used to evaluate the ergonomic quality of two chemical protective gauntlet gloves, the uvex rubiflex NB40S and the innovative AgiCSA gloves. Thanks to the results of the developed test methods, the necessary improvements to the AgiCSA gloves could be detected. The test results showed that the AgiCSA gloves achieved a better comfort level than the uvex gloves for most of the tested specifications. Nevertheless, the execution time of the test tasks was longer on average for the AgiCSA gloves than for the uvex`s product. This could be due to the unsuitable size of AgiCSA gloves in the thumb area or hand circumference, which need to be revised in further steps of this project.

REFERENCES

Allan, K. E., 2007. Evaluating Tactility and Dexterity for Military Aviation Protective Gloves. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, p. 1613–1616.

Barker, R. L., 2005. A Review of gaps and limitations in test methods for first responder protective clothing and equipment, Pittsburgh, PA, USA: Final Report Presented to National Personal Protection Technology.

Betts, G. L., 1946. Minnesota rate of manipulation test: examiner's manual.

BMBF, 2020. bmbf.de/sifo.de. [Online] Available at: https://www.sifo.de/sifo/en/research-projects/cross-cutting-issues-and-activities/knowledge-transfer-and-expertise-development/kmu-innovative-programm-for-innovative-smes/approved-joint-projects-funded-e-programm-for-innovative-smes.html [Accessed 28 03 2022].

CEPC, 2014. The Non-Binding Guidelines and Minimum Standards for CBRN First Responders (NBG/MS), s.l.: NATO`s Civil Protection Group - Civil Emergency Planning Committee (CEPC).

FwDV 500, 2012. Fire Service Regulation 500. Lübeck, Germany, Project group of board of firefighting affairs, catastrophe protection and civil protection (AFKzV).

Havenith, G., Hartog, E. d. & Martini, S., 2011. Heat stress in chemical protective clothing: porosity and vapour resistance. Ergonomics, p. 497–507.

Hines, M. & O'Connor, J., 1926. A measure of finger dexterity. Journal of Personnel Research, pp. 379-382.

ISO, 2020. ISO 21420:2020 Protective gloves — General requirements and test methods. 1 ed. s.l.:International Organization for Standardization.

Krausman, A. S. & Nussbaum, M., 2005. Effects of Chemical Protective Clothing on Task Performance Using Wearable Input Devices. Proceedings of the Human Factors and Ergonomics Society Annual Meeting, p. 651–655.

Nelson, J. B. & Mital, A., 1995. An ergonomic evaluation of dexterity and tactility with increase in examination/surgical glove thickness. Ergonomics, p. 723–733.

Ramadan, M. Z., 2017. The Effects of Industrial Protective Gloves and Hand Skin Temperatures on Hand Grip. International journal of environmental research and public health.

Schlueter, N., 2017. Der DyNamic-Ansatz: „Entwicklung eines Ansatzes zur verlässlichen Gestaltung von Unternehmensnetzwerken und ihren Produkt-Service-Systemen. Wuppertal, Germany: University of Wuppertal.

Schlueter, N., 2020. Redesign des Requirements Engineering in Netzwerken für Smart Products. In: Potenziale Künstlicher Intelligenz für die Qualitätswissenschaft:Bericht zur GQW-Jahrestagung 2018 in Nürnberg. Berlin, Heidelberg, Germany: Springer Vieweg.

uvex, 2022. www.uvex-safety.com. [Online]
Available at: https://www.uvex-safety.com/en/products/safety-gloves/6745/uvex-rubiflex-s-nb40s-chemical-protection-glove/
[Accessed 25 03 2022].

APPENDIX A - REQUIREMENTS FOR GLOVE FUNCTIONS WITH LINKED COMPONENT AND USAGE PROCESSES IN PROJECT "AgiCSA"

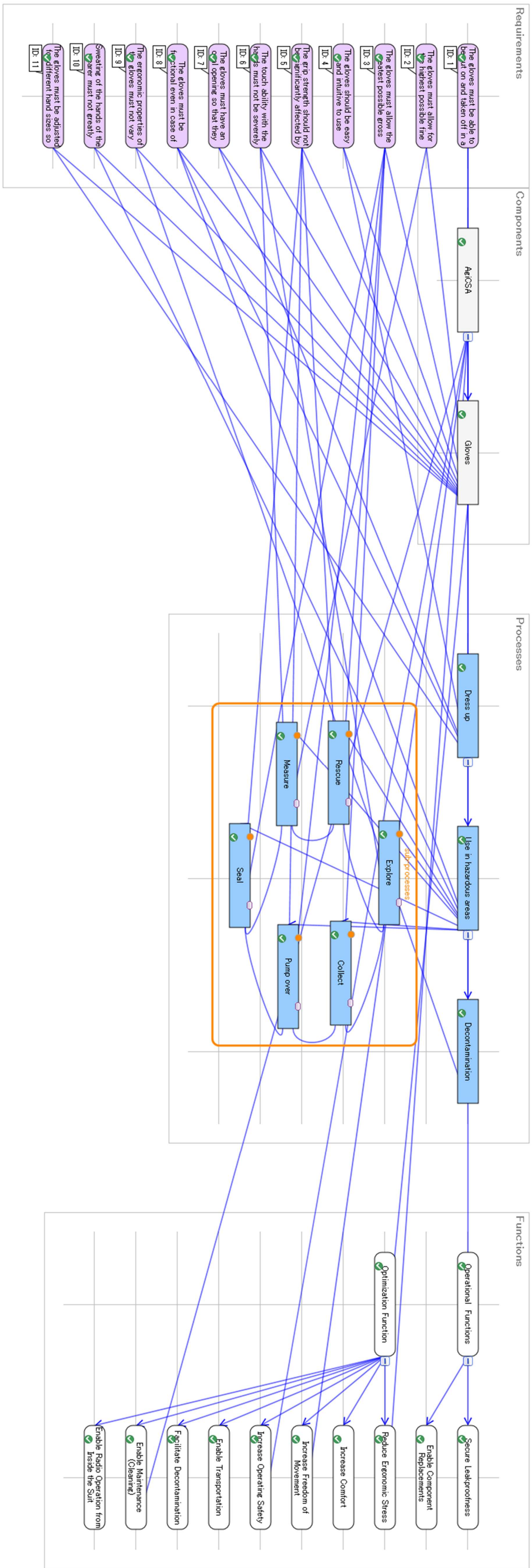

Figure 12 – DeCoDe Model created in iQUAVIS for the AgiCSA chemical protective gloves

Organization of a continuous improvement system in production companies

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STRUCTURED ABSTRACT

Purpose - The use of continuous improvement (CI) is closely related to the adopted management concept, which implies its importance and the level of application of specific improvement practices. The aim of the article is to: 1) define the level of importance of the applied improvement principles and values 2) indicate the application level regarding key improvement practices 3) indicate organizational solutions constituting a CI system used in manufacturing companies operating in Poland.

Design/methodology/approach – The research consisted of two parts. The first part was conducted with the use of literature analysis which allowed for the development of the questionnaire. The second part of study was carried out with the quantitative method using the telephone interview technique. 70 manufacturing companies operating in Poland participated in the study.

Findings - The article presents the results of the questionnaire research. The conducted research shows that CI, understood as a principle implemented within the framework of quality management, plays an important role in the development of the surveyed production companies. Particularly important practices include introducing the goals and tasks of continuous improvement into the company's business strategy and implementing them at lower levels of the organizational structure. Organizational units dedicated to conducting activities related to CI. The article also discusses their role and the level of application of tools initiating improvement activities.

Research limitations/implications- The limitation of the conducted research is the fact that it was conducted on a sample of 70 companies operating in Poland.

Originality/value - The presented issues have not previously been the subject of empirical research conducted among manufacturing companies operating in Poland. This will allow to indicate the current state and the direction of development of this approach.

Keywords: continuous improvement (CI), quality management, continuous improvement practices.

Paper type: Research paper

INTRODUTION

Continuous improvement (CI) practices are implemented in industries in order to optimize the process by minimizing waste and resource consumption. According to Fryer and Ogden (2014) many researchers believe that a modern organisation cannot build a high level of performance without a key ingredient that is continuous improvement. In the light of the transformations taking place in the industry towards Industry 4.0, the attention is also drawn to the fact that there is a need to amalgamate Industry 4.0 technologies with CI strategies to ensure significant benefits (Vinodh *et al.*, 2021).

CI practices such as Kaizen, Lean, Six Sigma and Lean Six Sigma have the ability to produce world class quality products (Dahlgaard and Dahlgaard-Park, 2006). The phrase “CI” is associated with a variety of organizational developments including the adoption of “lean manufacturing” techniques, total quality management (TQM), employee involvement programmes, customer service initiatives, and waste reduction campaign (Singh and Singh, 2015). CI is a vague concept that is susceptible of different interpretations (Boer and Gertsen, 2003). Two of them seem to be particularly significant, defining CI: as a set of practices and processes originating from an uninterrupted innovative flow, which stimulates the whole organisation towards sustainable excellence and as a set of competitive capabilities that allow organisations to learn, innovate and renew (Corso *et al.*, 2007). Continuous improvement can also be defined as improvement initiatives that increase successes and reduce failures or progressive amendment involving all company’s employees (Sanchez and Blanco, 2014). According to Suárez-Barraza *et al.* (2011) the most important principles and values of CI include: maintain and improve standards, focus on process, Gemba improvement management, leadership, people’s participation, teamwork, employee’s fulfilment and empowerment, training and education, the capacity use of highly experience veterans, customer focus, quality focus, base decisions on facts, remove muda, cross-functional approach. Acting in accordance with these principles creates a culture of continuous improvement and sets strategic goals for the organization. However, it requires organizational support and the use of specific practices allowing to achieve maturity in the implementation of the CI concept included in the CI Maturity Model (Dabhilkar *et al.*, 2007). They are related to: planning, organization, monitoring and improvement of the CI system at the operational level. On the other hand, the organization of improvement activities requires the appointment of people or teams responsible for the CI system and is associated with the definition of their responsibilities and tasks. A study by Galeazzo *et al.* (2017) explored the key dimensions of organisational infrastructure, namely strategic alignment and team working, and their impact on sustaining a CI capability. According to Anand *et al.* (2009) there are two key issues that impact the successful development of a CI capability. The first is the need to install procedures for the generation and implementation of CI projects in parallel with training people on problem solving techniques and process performance improvement practices. The second is the significance of taking a holistic view of the process of the CI initiative management (the collection, review and implementation of ideas generated as part of CI activities) (Butler *et al.*, 2018).

According to Singh and Singh (2015) (who presented the overview of various CI implementation practices demonstrated by manufacturing organizations) globally CI programmes have evolved from traditional manufacturing focused systems that concentrate on the production line to reduce waste and improve the product quality, into comprehensive, systematic methodologies that are focused on the entire organization. A problem which emerges from a literature study is, that there is no general consensus among practitioners and researchers regarding a particular recommended route to the implementation of CI . Moreover, achievement of the expected results of modern day CI programmes is quite challenging as it involves organizational changes on many levels. Despite the benefits, these can bring continuous improvement efforts, which are consistently reported to have a high failure rate (McLean *et al.*, 2017). One of the reasons of these errors is that the organisations' social aspects are underestimated (Moosa and Sajid, 2010). The structure of the organisation could also influence the change efforts. Organisations could find themselves unable to put the desired changes into practice due to hierarchical management structures (Venkateswarlu and Nilakant, 2005). Moreover CI implementations are not the easiest ones, especially when CI tools and techniques are emphasized, neglecting the use of appropriate behaviour patterns (Dabhilkar *et al.*, 2007).

Whereas Rodgers *et al.* (2021) pay attention to the readiness factors of organizations for a CI which have been defined as 'essential ingredients, which will increase the probability of success of any CI initiative before an organization invests its resources heavily on the initiative'. According to Lameijer *et al.* (2021), after each phase in the implementation of CI, readiness for the next phase needs to be assessed. The CI implementation is fundamentally a learning process, where outside practices are implemented, and their results evaluated. Therefore, it is important to conduct empirical research concerning social aspects, including the extent to which the principles and values of continuous improvement are applied in enterprises, what practices are implemented and what organizational solutions are used in the context of improvement activities.

It should be emphasized that although the study of continuous improvement started a long time ago, initially in the USA then in Japan, little is known about the CI's state-of-the-art in Europe (Corso *et al.*, 2007). Corso *et al.* (2007) conducted research among Italian companies regarding: the CI tools and enablers adopted in Italy, the state of the improvement activities and their evolution, the relations between CI tools, ability development and performance. A survey was conducted in The Netherlands in order to gain insight into current practices and the evolution of continuous improvement. The study showed, that it is difficult for companies to design and implement an approach towards continuous improvement that is in line with their own perceptions (Middel *et al.*, 2007). Jaca *et al.* (2012) have aimed at evaluating the importance of the factors reported in the literature as enablers of CI programmes and to determine the perception of managers of different companies in Spain regarding the relevance of these factors to their improvement programmes. The investigation, regarding the barriers that exist while implementing continuous improvement methodologies, such as Lean Six Sigma (LSS), within the Irish Pharmaceutical industry has been conducted by McDermott *et al.* (2022).

It is also worth paying attention to the results of research conducted among 15 UK organisations. This research proves the significance of the causal relationship between the CI Leadership competences and the effectiveness of the CI Capability within an organisation, thus filling an important gap between established previous work focussing on the role of mid-level management on one side and the practitioner and team's level roles, methodologies and tools. Organisations working to develop their CI capability should recognise the importance of both the CI Environment, and the critical role and influence that mid-level managers hold within this environment (Fannon *et al.*, 2022).

Research on CI has been conducted in several countries outside of Europe. Terziovski and Power (2007) tested the strength of CI in finding out the relationship between motivation for seeking ISO 9000 certification, quality culture, management responsibility, and the perceived benefits derived from ISO 9000 certification. Nevertheless the generalizability of the results may be limited to the Australian context. Oprime *et al.* (2011) have identified and analyzed the critical factors in the development of CI activities in 46 Brazilian companies. Comparing the practices of continuous improvement that are applied in medium and large manufacturing and service companies in two Latin American countries: Mexico and Ecuador was carried out by Alvarado-Ramírez *et al.* (2018). Sunder and Prashar (2020) studied the critical failure factors of CI deployments based on stage-wise results. Findings reveal significant differences in the occurrence of critical failure factors across countries, where the research was conducted, namely: USA, UK, China and India.

To the best of the author's knowledge, the development of CI was not researched in manufacturing companies operating in Poland. No quantitative research has been conducted on organizational CI solutions used in enterprises, and the level of the principles application and CI values has not been investigated. Identification of the research gap prompted the authors to raise the following research questions:

- RQ1. To what extent are the principles and values of CI applied in manufacturing companies operating in Poland?
- RQ2. To what extent and with what commitment are key improvement practices applied in manufacturing companies operating in Poland?
- RQ3. What organizational solutions related to the CI system are used in manufacturing companies operating in Poland?

The aim of the article is to: 1) define the level of importance of the applied improvement principles and values 2) indicate the application level regarding key improvement practices 3) indicate organizational solutions constituting a CI system used in manufacturing companies operating in Poland.

The remainder of this paper is organized as follows: section 2 contains research methodology; section 3 describes results of research. The soundest conclusions and future research opportunities are presented in the final section.

RESEARCH METODOLOGHY

The research consisted of two parts: literature analysis and the quantitative method using the telephone interview technique with the use of the questionnaire developed by the authors of the publication (Fig. 1).

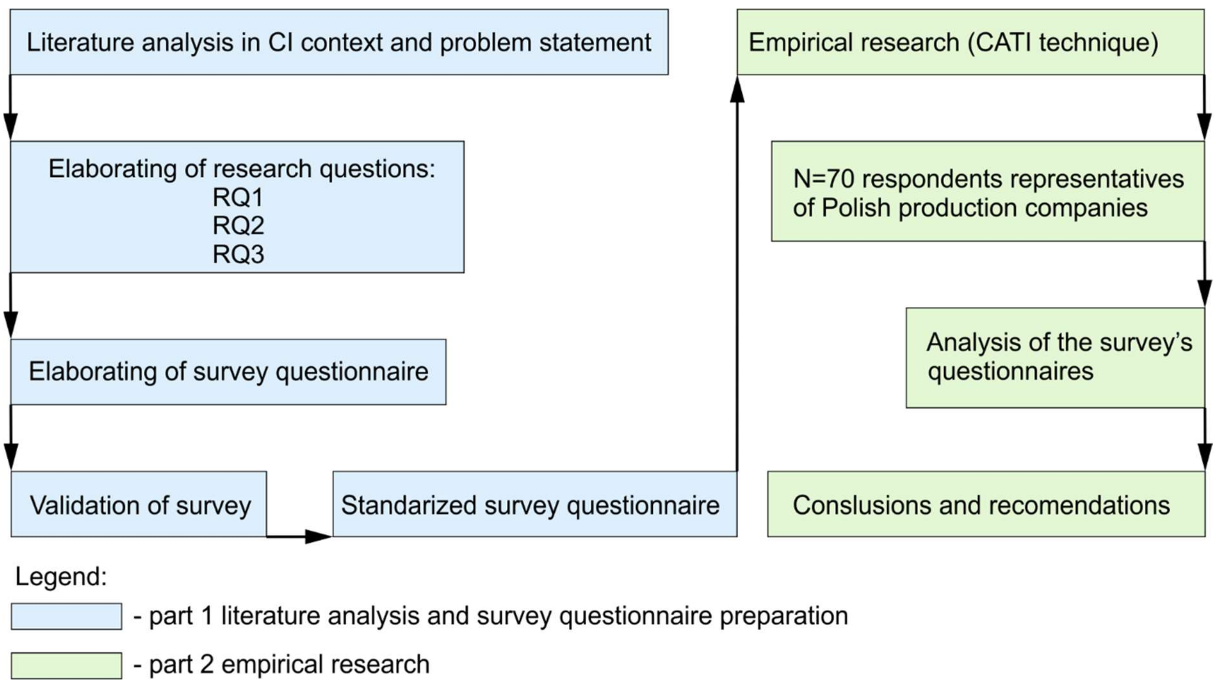

Figure 1 – Scheme of the conducted research.

The literature review had been used by the authors to develop the questions of the survey, which was used in empirical research aimed at examining the improvement activity in manufacturing enterprises. The finally developed survey consisted of three parts, which aimed to analyze such issues as: principles and values of CI (goal 1 of this article), identification implemented key improvement practices (goal 2) and organizational structure in the context of improvement actions (goal 3).

In order to research the principles and values of CI potential answers to the question regarding such principles as:

- maintain and improve standards (P1),

- focus on process (P2),
- Gemba improvement management (P3),
- leadership (P4),
- people's participation (participation of all employees) (P5),
- teamwork (P6),
- employee fulfillment and empowerment (P7),
- training and education (P8),
- use the capacity of highly experience veterans (P9),
- customer focus (P10),
- quality focus (P11),
- base decisions on facts (P12),
- remove muda (P13),
- cross-functional approach (P14).

The respondents assessed each principle in 6 (where 0 was not used, 1 was low, 2 was basic, 3 was medium, 4 was high, 5 was very high; however, if not used, the level of importance was not checked) and 5 degrees a scale (meaning: 1 very little, 2 a little, 3 a little bit, 3 a little bit, 4 a lot, 5 very much), respectively, for the degree of application and the level of importance.

The second part of the survey concerned key improvement practices. The analysis of the literature allowed for the identification of key improvement practices that constitute the organization and maintenance of the enterprises' continuous improvement system. These include the following enablers:

- a designated person or group monitors the CI system, measures the scope and results of improvement activities (E1),
- a cyclical planning process is carried out, the CI system is regularly checked and, if necessary, changes are introduced (E2),
- periodic review of the CI system is carried out for the organization as a whole, which can lead to a significant regeneration of the system itself (E3),
- senior management makes sufficient resources (time, money and personnel) available to support the continual development of a CI system (E4),
- employees use some kind of formal (structured) cycle of searching and solving problems (E5),
- improvement actions are included in everyday activities, they are not only occasional/sporadic actions (E6),
- employees (individually and/or collectively) evaluate the proposed changes in relation to the goals of the department or the company's goals in order to ensure the compliance of the changes with these goals (E7),

- employees have a full autonomy in terms of experimenting and making improvements within their workplaces (E8),
- the organization uses specific mechanisms to implement learning, acquiring and transferring knowledge in relation to all CI activities (E9),
- the company has clearly defined goals and tasks to guide the process of CI (E10),
- the goals and tasks of the CI process are in line with the company's business strategy (E11),
- the goals and tasks of the CI process are communicated to all employees (E12),
- the goals and objectives of the CI process are implemented at lower levels of the organizational structure (E13),
- specific sets of indicators are used to manage all improvement activities (E14),
- indicators are grouped and displayed in one scorecard, which is used to manage the CI process (E15),
- the company uses a formal system to manage and control all improvement activities (E16).

To assess the extent to which key improvement practices are applied in the organization, a 5-point scale was used, where 0 means not applicable, 1 to a very small extent, 2 is used selectively in selected areas of the company, 3 is used throughout the company, but on a different basis. level of commitment, 4 is used with great involvement of employees at all levels of the company, 5 is used with great involvement of employees at all levels of the company.

With regard to the analysis of the area, related to the organizational structure in the context of the improvement activities undertaken (the third part of the survey), it was based on the fact that activities related to the enterprise's continuous improvement require organizational support, which may include the following:

- people responsible for the continuous improvement system throughout the organization (A1),
- an organizational unit dealing with continuous improvement (A2),
- people responsible for continuous improvement at mid-levels of the organizational structure (A3),
- continuous improvement teams (A4),
- quality circles (A5),
- other organizational solutions (A6).

Here, the respondents were asked to choose the solutions used in their enterprise (multiple choice). In the aspect of organizational solutions supporting CI, it is equally important to determine to what extent a person or office appointed to deal with continuous improvement in the company is involved in individual tasks, therefore respondents were also asked about issues related to:

- developing a CI program (I1),

- implementing and coordinating the CI program (I2),
- creating schedules and action plans (I3),
- promoting a culture of CI (I4),
- cooperation with employees of the entire company in the area of the improvement process (I5),
- administration and coordination of improvement projects (I6),
- planning and organizing improvement projects (I7),
- assisting in organizing meetings as part of improvement projects (I8),
- implementation of new and improvement of the current process improvement tools (I9),
- taking actions to improve business processes (I10),
- conducting trainings and workshops in the field of CI as well as the introduced techniques and tools for continuous improvement (I11),
- conducting trainings and workshops in the field of CI as well as the introduced techniques and tools for CI (I12),
- coordinating the operation of the suggestion system by registering the ideas submitted (I13),
- participation in verification and evaluation as well as monitoring the implementation of accepted ideas (I14),
- conducting analysis and summaries of results (I15),
- preparing and conducting presentations (I16),
- cooperation with the person responsible for quality management (I17).

While researching the organization of improvement activities, attention was also paid to the issue of initiating improvement activities. The following were considered potential sources:

- top management ideas (PS1),
- middle managers ideas (PS2),
- ideas from the suggestion system (PS3),
- quality management system audits results (PS4),
- assessment of the results achieved (PS5),
- customer satisfaction assessment (PS6),
- 5S audit results (PS7),
- TPM audit results (PS8),
- external audit results (PS9),
- self-assessment results (PS10),
- internal benchmarking (PS11),
- external benchmarking (PS12),
- external customers opinions (PS13).

Regarding the three questions above, the authors used a 5-point scale marked as: 1 to a very small extent, 2 to a small extent, 3 to an average extent, 4 to a large extent, 5 to a very large extent.

The quantitative method was used in the research. The survey was carried out in November 2020, using the CATI technique, i.e. computer-aided telephone interview. It is a technique preferred for the implementation of supra-regional research, due to the ease of reaching a relatively large, geographically dispersed group of respondents, while maintaining a short implementation time. The survey was carried out in a cascade, first a pilot survey was carried out among respondents - representatives of manufacturing companies. Its purpose was to verify the correctness of the research tool, its structure, and the level of the questions' understanding, which had been included in the survey questionnaire. As a result of the pilot test, the original version of the questionnaire was improved by removing questions that were not understood by the respondents (it was considered that their structure was too scientific) and those that turned out to be questions about the same issue, albeit in a different way. The thus corrected questionnaire was used for the main empirical study. The tool, which was used in the research, was a standardized interview questionnaire. It consisted of 5 substantive questions, closed (i.e. with a predefined cafeteria of answers) or built on the basis of a scale. The questionnaire also took into account 5 metric questions, allowing to characterise the surveyed and the enterprises they represent. The obtained Cronbach's alpha reliability coefficient, representing the result of the questionnaire used in the study, represents at a high level - 0.981 (on a scale of 0 to 1, where the higher the value, the greater the reliability of the questionnaire).

A total of N=70 people participated in the survey - representatives of Polish production companies responsible for the quality management, the use of continuous improvement methods or management in the organization. The survey conducted among 70 enterprises was aimed at the achievement of the goal presented in the introduction of the article. The key to the selection was the fact that the enterprise conducts production activity, and the indicated role of the respondent was important. Quality management representatives accounted for over one third of all respondents (37.1%). Every fourth respondent held a senior management position (25.7%); leaders, coordinators and quality management specialists (25.7%) participated in the study at the same time. Plenipotentiaries for the integrated management system (8.6%) and members of the management board (2.9%) also participated in the survey.

The vast majority, i.e. over 84% of the surveyed companies, are medium-sized enterprises, employing from 50 to 249 people. Every tenth surveyed enterprise is a small company with 10 to 49 employees. Large companies employing over 249 people accounted for less than 6% of the research sample. The respondents were dominated by companies operating in the electromechanical industry (i.e. metal, machinery, precision, means of transport, electrical engineering or electronics); they accounted for

40% of the surveyed enterprises. Another 30% of the surveyed companies operate in the wood and paper industry, 20% in the food industry, and every tenth - in the cosmetics industry.

RESULTS

Principles and values of CI

The first part of the study concerned the degree of application and the importance to the organization of the principles and values of the continuous improvement (Fig. 2). The highest ratings relating to the usage degree were most often given by the respondents to the ‘customer focus’ (P10) (52,9%[1]) and ‘quality focus’ (P11) (51,4%[2]). The highest number of the lowest ratings – ‘1’and ‘2’ was assigned by the respondents to the ‘people’s participation’ (P5) (31.5%) and to ‘maintain and improve standards’ (P1) (27.2%). The principle and value that most often does not apply is the improvement management at the point of ‘Gemba improvement management’ (P3) (10.0%).

The degree of application of specific principles and values and the level of their importance for the first two values: ‘customer focus’ and ‘quality focus’ are consistent with each other. The ‘customer focus’ and the ‘quality focus’ were assessed as important to a large or very large extent by the largest number of respondents (62.8% and 58.6%, respectively). The lowest grades (expressed in ratings ‘1’ and ‘2’) were awarded to ‘cross-functional approach’ (P14) (18.6%) and ‘leadership’ (P4) (18.6%).

[1] When combining the answers ‘4’ and ‘5’.
[2] as above.

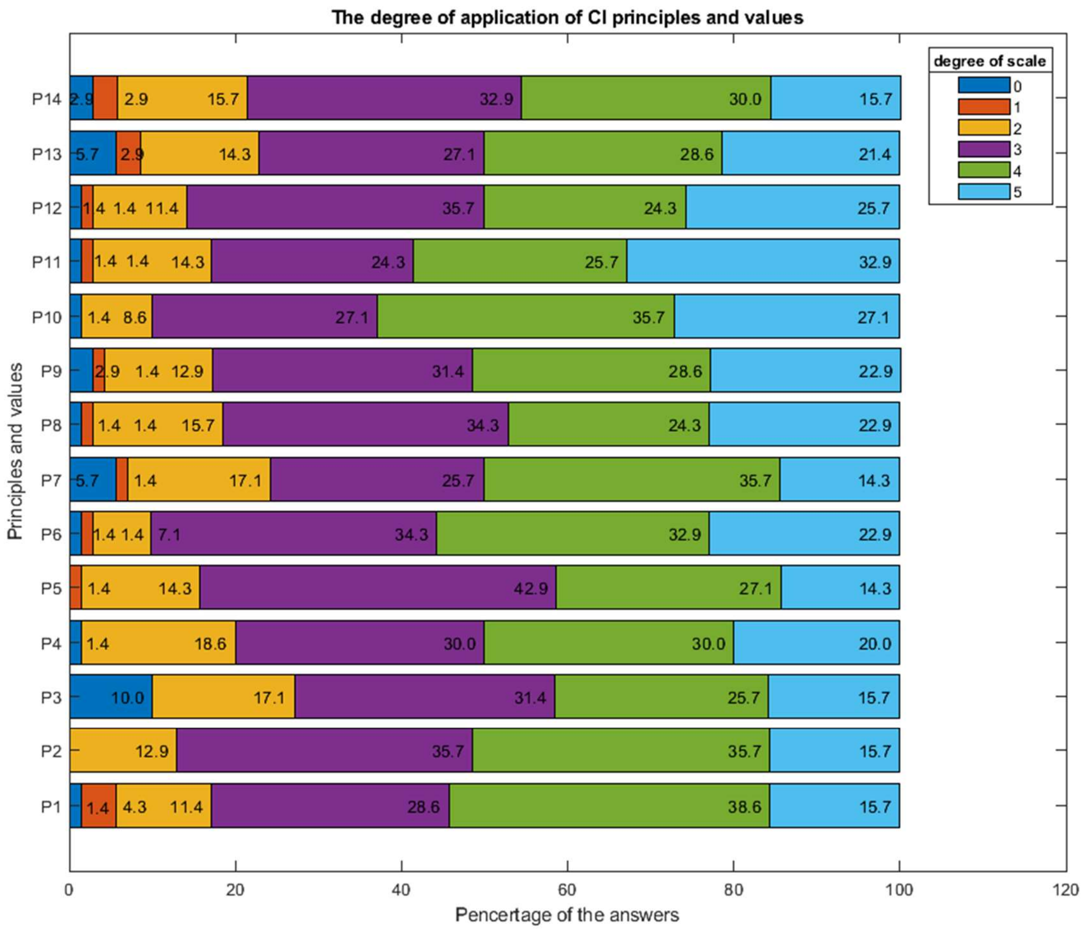

Figure 2 – The degree of application of CI principles and values.

The degree of application of individual principles and the value and the level of their importance were subjected to the chi square statistical test. It did not show a relationship between the degree of application of a given value and the level of its importance.

The importance of all the discussed elements was highly rated; the average scores exceeded 3 points (Fig. 3). The respondents attached the greatest importance to ‘customer focus’ (P10) (m = 3.77) and ‘quality focus’ (P11) (m = 3.70). Highly appreciated values are also ‘teamwork’ (P6) (m = 3.64) and ‘base decisions on facts’ (P12) (m = 3.57). The lowest, but also of a high importance, was attached by the respondents to ‘employee fulfillment and empowerment’ (P7) (m = 3.27) and to the ‘Gemba improvement management’ (P3) (m = 3.10).

The level of application of individual principles and the value of continuous improvement in enterprises was assessed slightly lower than its importance (Fig. 3). ‘Quality focus’ (P11) is a principle that is currently used most often in the surveyed enterprises (m = 3.57); second, it is the ‘customer focus’ (P10) (m = 3.47). The ‘people’s participation’ in the functioning of the enterprise is one of the two least implemented principles (P5) (m = 3.00); the second is the ‘Gemba improvement management’ (P3) (m = 2.74).

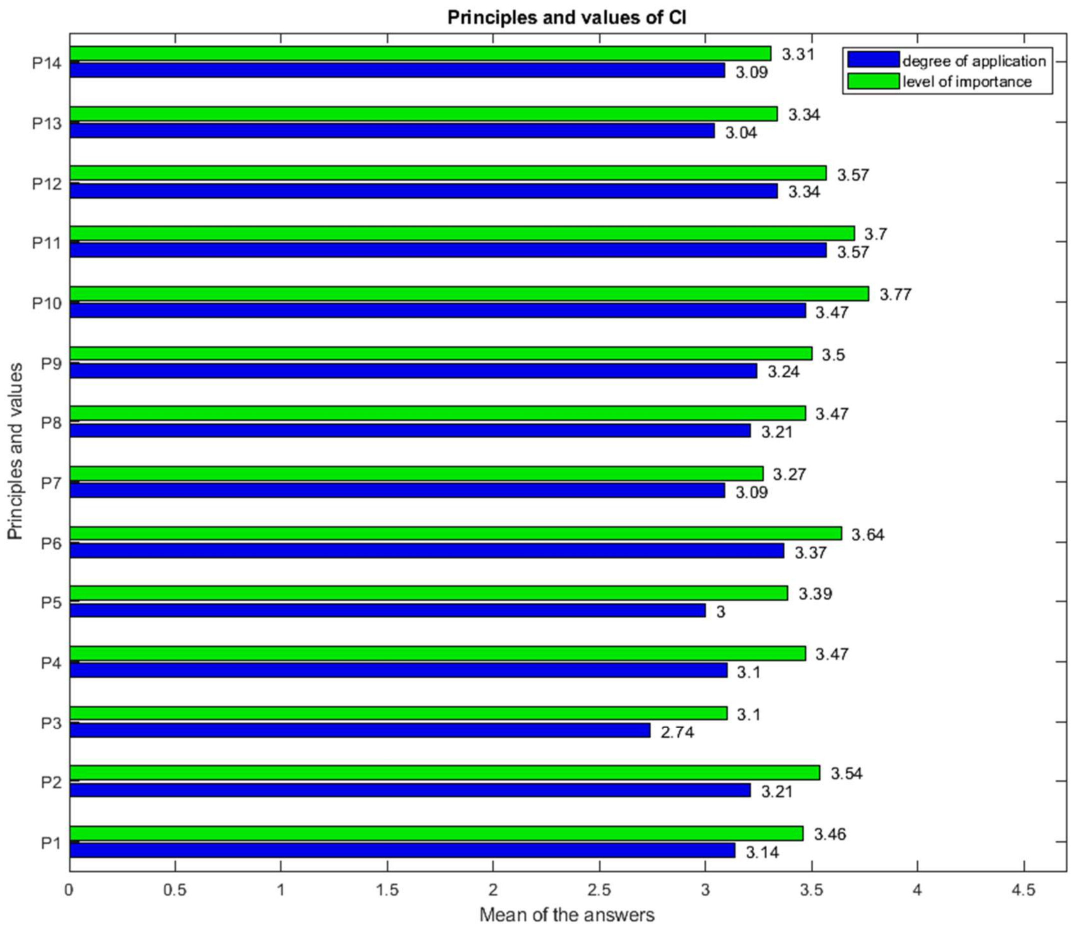

Figure 3 – Application and importance of the principles and values of continuous improvement in the organization; scale [0;5]; N=70.

Identification implemented key improvement practices

In the second part of the study, the respondents replied to individual statements relating to the key improvement practices of the continuous improvement system, that is operating in their companies (Fig. 4). The greatest compliance with a given statement was found in the sentence 'Indicators are grouped and displayed in one scorecard, which is used to manage the continuous improvement process' (E15) (31.4%[3]) and 'The goals and objectives of the continuous improvement process are implemented at lower levels of the organizational structure' (E13) (28.6%). The smallest degree of application (expressed in ratings '1' and '2') occurred in relation to the sentence 'The goals and tasks of the CI process are communicated to all employees' (E12) (45.7%).

[3] When answers '4' and '5' are combined.

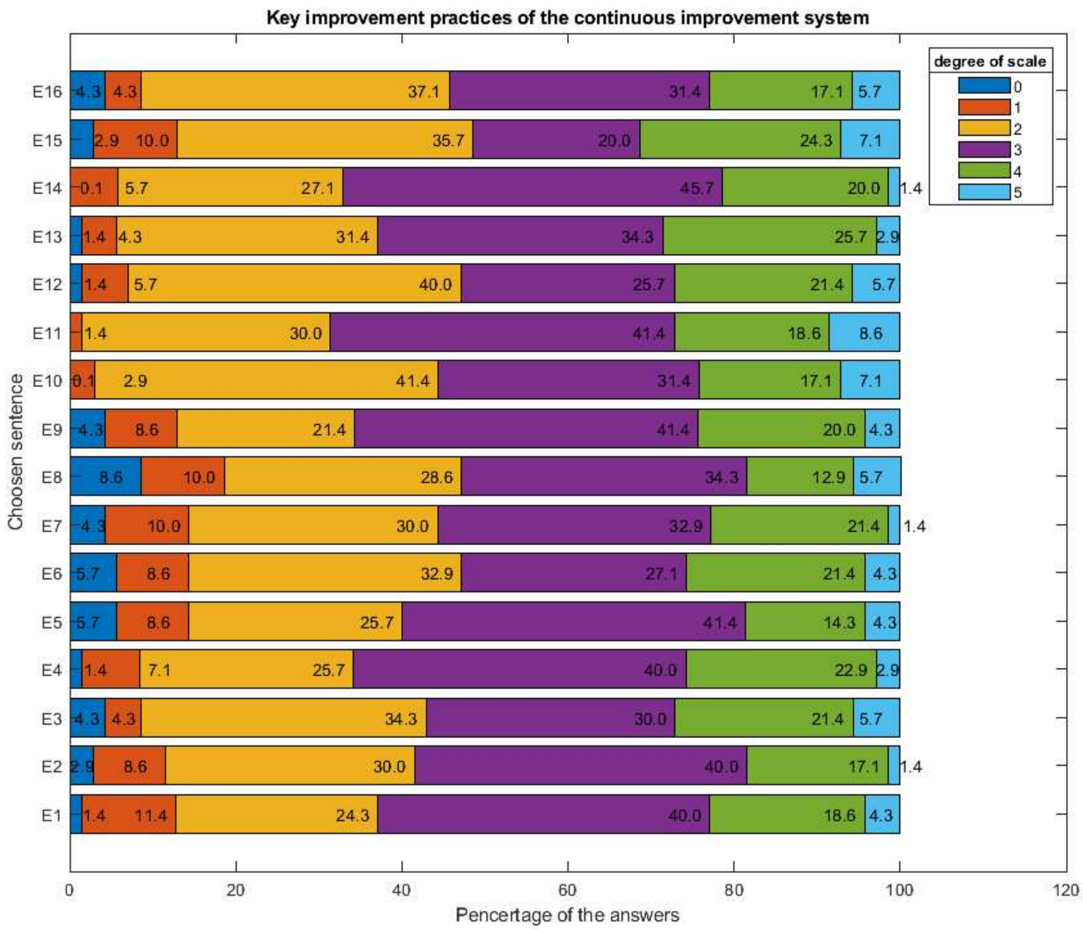

Figure 4 – Opinions on continuous improvement in the enterprise, N=70.

Interestingly, the average level of consent with all the presented statements was similar, ranging from 2.5 to 3 points (Fig. 5) - this indicates a different level of commitment of individual employees to the implemented solutions, and thus, room for development, primarily in the area of persuasion introduced for CI processes.

The most commonly used and accepted statement was that the goals and objectives of the continuous improvement process were included in the company's business strategy (m = 3.03). The respondents also declare that relatively often and with commitment, these goals and tasks are implemented at lower levels of the organizational structure (m = 2.87). At the same time, the lowest level of acceptance of the respondents was obtained by the statement that employees had full autonomy in terms of experimenting and introducing improvements within their workplaces (m = 2.5).

Analysing the respondents' replies, according to the level of consent they had declared with individual statements, the conclusion is drawn that while continuous improvement is a strategic goal of many companies, the use of specific tools related to it and internships as well as employee's empowerment are areas that require an in-depth work.

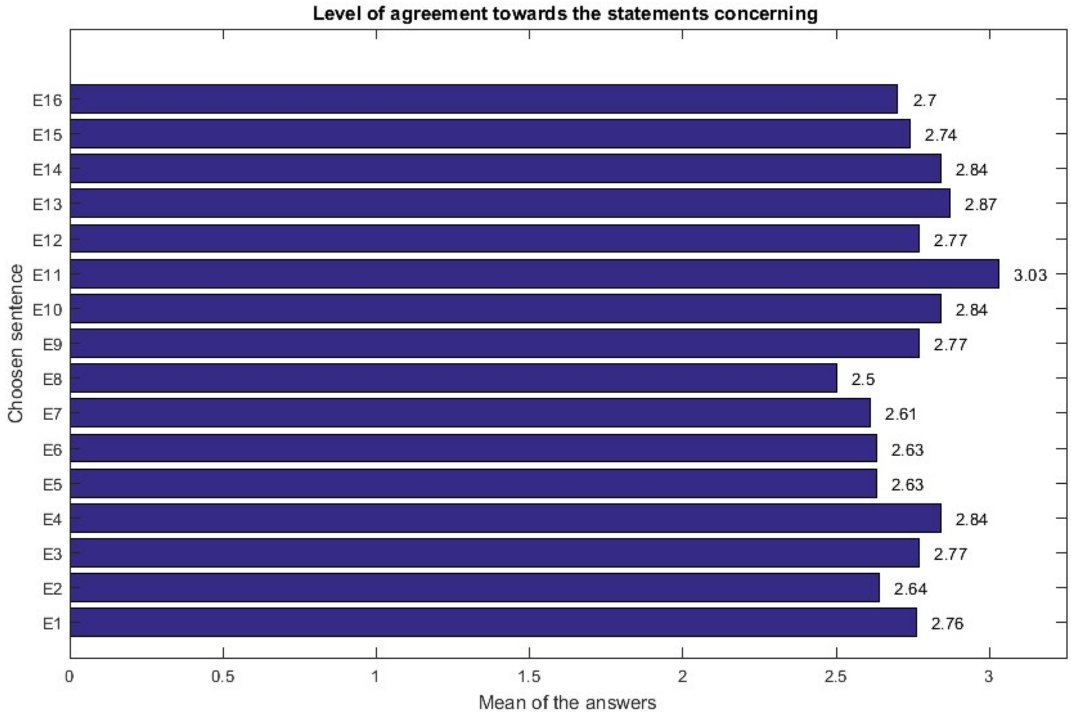

Figure 5 – Level of agreement towards the statements concerning continuous improvement in the enterprise; scale [0;5]; N=70.

Organizational solutions

The third part of the empirical study was related to the analysis of the organizational structure in the context of improvement activities undertaken by the company (Fig. 6). The most frequently indicated organizational solution related to the continuous improvement process in the surveyed companies was the separation of a unit dealing with CI in the structure of the company; they were implemented by 40% of the surveyed entities. In nearly every fourth company (23%), there were particular people, responsible for the continuous improvement at the middle levels of the organizational structure, while in almost every fifth (19%) - there was a person responsible for the continuous improvement system in the entire organization. 13% of respondents also indicated the separation of continuous improvement teams. The least popular solution turned out to be the so-called quality circles, selected in 6% of the surveyed enterprises. In the case of the analysis of the organizational solutions used, it was possible to indicate several of them, adequately to the practices implemented in enterprises.

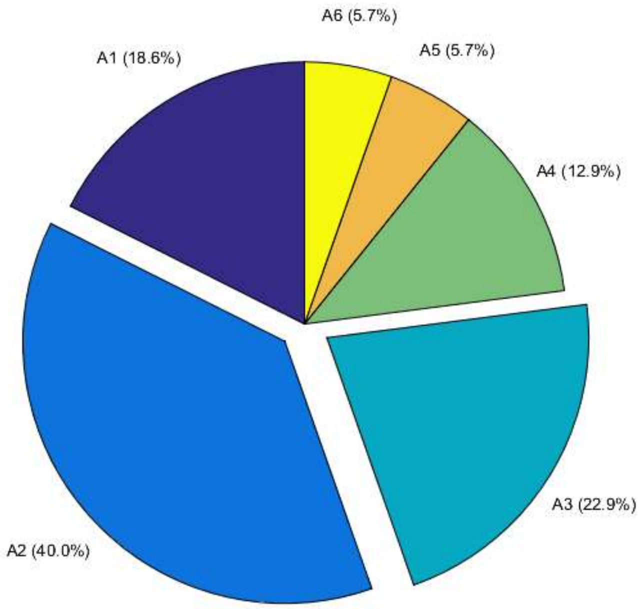

Figure 6 – Organizational solutions applied in the enterprise; N=70.

On the other hand, the respondents' replies to the extent to which a person or an office established in order to deal with continuous improvement in the company is engaged in individual tasks indicate, that the person responsible for this type of activity in the enterprise, to a large or a very large extent, is most often involved in administration and coordination of improvement projects (I6) (40.0%[4]), creating schedules and action plans (I3) (37.2%) and developing a program of continuous improvement (I1) (37.1%). Most often, the person is not concerned with such tasks as: coordinating the operation of the suggestion system by registering submitted ideas and developing a continuous improvement program (I12) (35.7%).

With regard to the office, which is responsible for continuous improvement in the company, it most often participates, to a large or a very large extent, in cooperation with the person responsible for quality management (I16) (54.3%[5]) and helps in organizing meetings as part of improvement projects (I8) (51.5%). The office, to a small or very small extent, participates in cooperation with employees of the entire company in the area of the improvement process (I5) (12.8%) and in the implementation and coordination of the continuous improvement program (I2), as well as in the development of a continuous improvement program (I1) (10.0%).

The answers of the respondents also reveal that all tasks involved individuals and organizational units responsible for them to a comparable, moderate degree (Fig. 7). However, it can be concluded that

[4] When combining answers '4' and '5'.
[5] as above.

the level of involvement of offices responsible for the continuous improvement in individual tasks was slightly higher than in case when the particular individuals were responsible for them (m = 3.70 vs m = 3.46). The biggest difference in the level of people's involvement and offices responsible for continuous improvement, concerned cooperation with employees of the entire company in the area of the improvement process. A fairly large difference is also noticeable in the task of implementing and coordinating the continuous improvement program. These tasks are undoubtedly crucial for the development of the CI concept, therefore their enhancement may have a significant impact on the effectiveness of improvement actions.

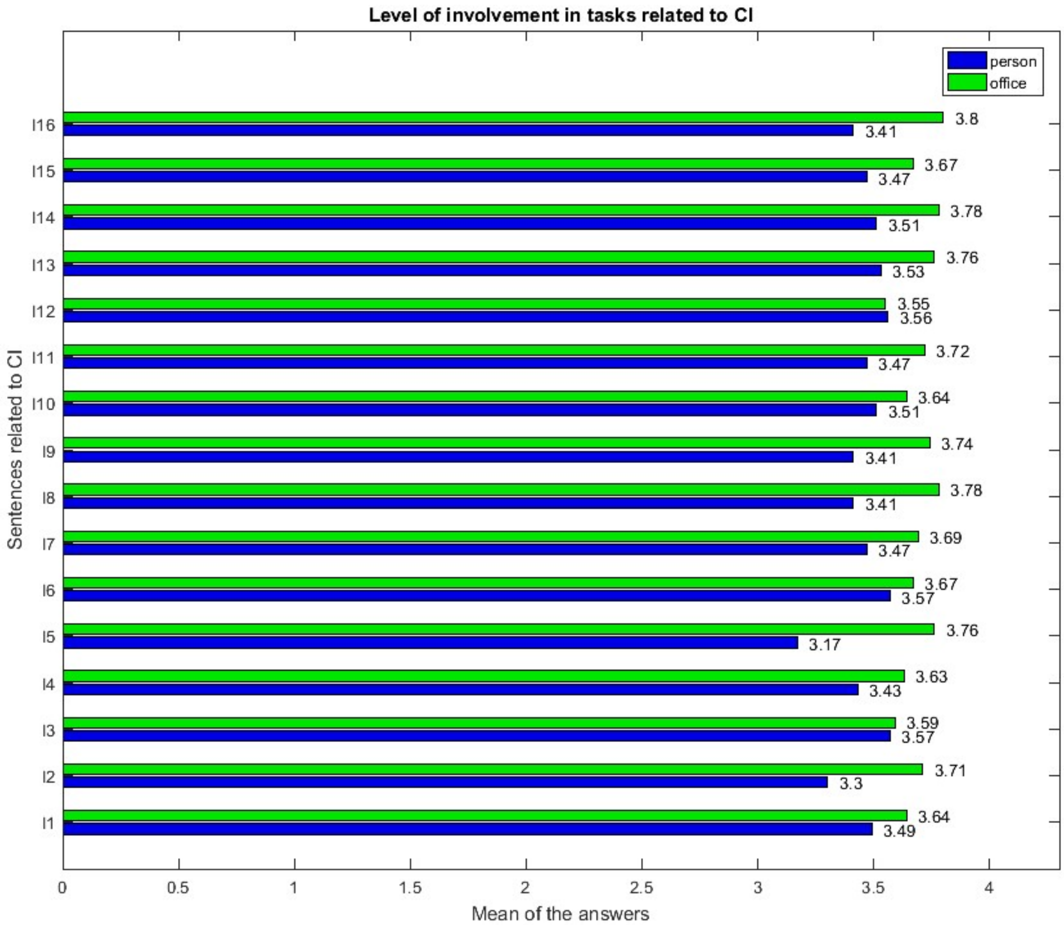

Figure 7 – Level of involvement in tasks related to the continuous improvement system; scale [1;5]; N=70.

Taking into account the research results, it can be concluded that enterprises wishing to develop activities related to continuous improvement should place emphasis on good organization of this area and strengthen it by appointing an organizational unit responsible for numerous tasks indicated above.

The research results in the context of the source of the initiation of improvement actions indicate that among the tools that are most often used to initiate improvement actions in the surveyed enterprises are (Fig. 8):

- Customer's Satisfaction Assessment (PS6) (65,8%[6]),
- Assessment of the achieved results (PS5) (65.7%),
- External customers' opinions (PS9) (55.7%).

Much less important are:

- TPM audits results (PS8) (22,9%[7]),
- 5S audits results (PS7) (20.0%).

As the obtained responses show - the customers' feelings and their satisfaction are more crucial for enterprises than the results of conducted audits.

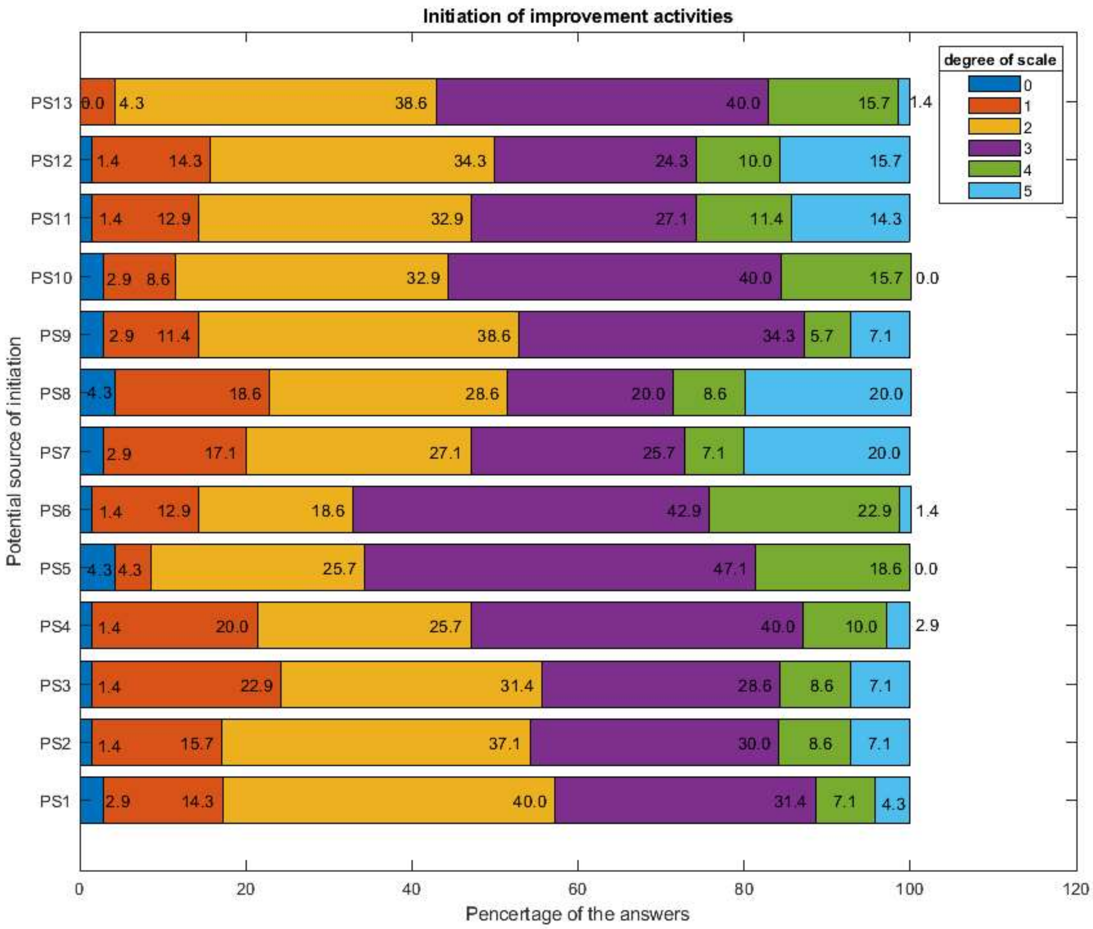

Figure 8 – The degree of initiation of improvement actions by the indicated tools, N=70.

[6] When combining answers '4' and '5'.
[7] When combining answers '1' and '2'.

All the analysed factors that may trigger perfecting actions were of comparable importance for the respondents (Fig. 9). Most often, however, the respondents admitted that the undertaking of activities related to the improvement in the company was influenced by the customer's rating (PS6) (m = 3.74), the evaluation of the results achieved (PS5) (m = 3.71) or the external customers' opinions (PS9), but not taking the form of a formal evaluation (PS9) (m = 3.68). The least important factors are the results of job audits (PS7) (5S, m = 3.21) and the effectiveness of the machine park (PS8) (TPM, m = 3.13).

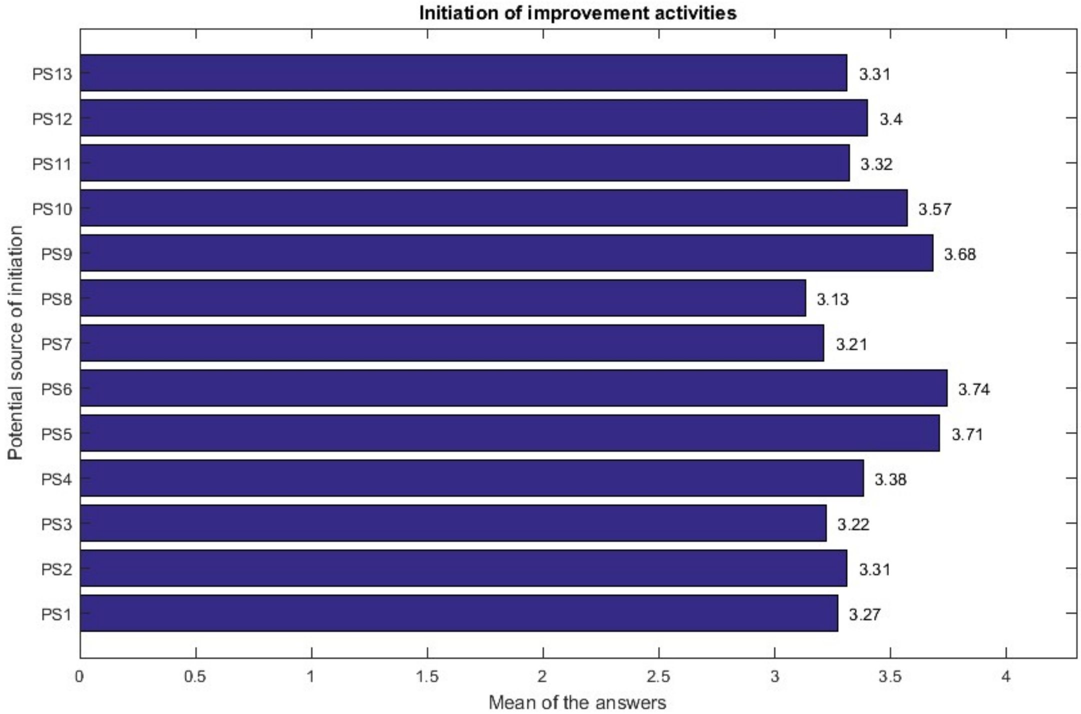

Figure 9 – Initiation of improvement activities; scale [1;5]; N=70.

CONCLUSIONS

The organization's important goal, apart from the professional activity, is the process optimization, among others by minimizing waste or resource consumption. Therefore, it is important, for modern organizations, to use practices of the continuous improvement (CI) in a proper and effective manner, which is emphasized, among others, by Fryer and Ogden (2014). Equally important is the observation of Singh and Singh (2015), that in the modern approach, the practice of CI has evolved and does not focus only on the production line, but comprehensively covers the entire organization, thanks to which they constitute systematic methodologies. However, the achievement of the expected results of contemporary CI programs is quite difficult because it is associated with organizational changes on many levels, as noted by researchers such as Venkateswarlu and Nilakant (2005) or Dabhilkar *et al.* (2007). Empirical research by Corso *et al.* (2007) and McLean *et al.* (2017) confirms this problem. The aim of the article is to: 1) define the role and the importance level of the applied principles of improvement and value practices, 2) indicate the application level of key improvement practices, 3) indicate organizational solutions that make up the continuous improvement system used in manufacturing companies operating in Poland. To complete the goals mentioned above, on the basis of the literature review, a survey was developed, which included three parts, which aimed to analyse such issues as: principles and values of CI (goal 1 of this article), identification of the implemented key improvement practices (goal 2) and organizational structure in the context of improvement activities which were undertaken (goal 3). Then an empirical study was carried out using the CATI technique, i.e. a computer-aided telephone interview attended by 70 representatives of organizations operating in the territory of Poland.

Based on the respondents' answers, appropriate conclusions were obtained regarding the formulated main aims of the article. In the view of the application degree assessment and the significance of the principles and the value of CI (goal 1) for the organization, one of the most important and promoted ones should be included in the form of: 'customer focus' and 'quality focus'. The principle and value that is most often neglected and which is also the least frequently implemented is 'Gemba improvement management'. In addition, the application level of individual principles and the value of continuous improvement in enterprises were assessed slightly lower than its importance. It means, therefore, that awareness is growing in the context of the importance of the implementation of particular CI principles and values, however, there are still some difficulties or limitations in maintaining an appropriate level of their use. It is worth noting that the principles that are applied on an average level also include leadership, which indicates an area that requires special reinforcement. According to Fannon *et al.* (2022) there is the positive relationship between the mid-management, CI Leadership competences and the effectiveness of the CI Capability, which informs about the strategic organisational development interventions towards enhancing CI capability and effectiveness, ultimately underpinning productivity enhancement and sustainability.

In turn, from the point of view of the key improvement practices level (goal 2), definitely the goals and tasks of the CI process are in line with the company's business strategy, and the goals and objectives of the CI process are implemented at lower levels of the organizational structure. Equally important are the facts that: specific sets of indicators are used to manage all improvement activities; the company has clearly defined goals and tasks to guide the process of CI and senior management supplies sufficient resources (time, money and personnel) available to support the continual development of a CI system. However, this is still only an average level, meaning they are used throughout the company, but at a different level of commitment. Moreover, respondents indicated the selective use (in selected areas) of such key practices as: employees use some kind of formal cycle of searching and solving problems; improvement actions are included in everyday activities; employees evaluate the proposed changes; employees have full autonomy in terms of improvements within their workplaces.

This indicates employees' moderate improvement activity, who perform in the area of operational processes, which may hinder the implementation of the Gemba improvement management principle and the principles of people's participation, teamwork and employee's fulfilment and empowerment. It may also cause difficulties in reaching maturity in the CI area included in the 'CI maturity model' (Fryer and Ogden, 2014).

With regard to issues related to the organizational structure in the context of the improvement activities undertaken in enterprises (goal 3), the most common approach is, where a unit dealing with CI has been separated in the company's structure. Then most often the person responsible for continuous improvement is a representative of the middle level of the organizational structure. The person responsible for CI in the enterprise is most often involved in the administration and coordination of improvement projects, creating schedules and action plans, and developing a continuous improvement program. At the same time, this person is not concerned with such tasks as: coordinating the operation of the suggestion system by registering the submitted ideas and the development of a continuous improvement program. The source of the initiation of the improvement actions are customers' opinions and evaluation of the achieved results. In the case of an office, it most often participates in cooperation with the person responsible for quality management and supports in arranging meetings as part of the improvement projects. Simultaneously, to a small or a very small extent, participates in cooperation with employees of the entire enterprise in the area of the improvement process as well as in the implementation and coordination of the continuous improvement program, it is also little involved in the development of the continuous improvement program. The level of offices' involvement is slightly higher than that of individuals, and the biggest difference concerned cooperation with employees of the entire company in the area of the improvement process. The least popular organizational solution turned out to be the so-called quality wheels. Therefore, this confirms the conclusions of aim 2 of the article, where still not all employees are involved in the CI process, but only a narrow group directly responsible for the CI activities. This area related to the organizational structure needs support as, according to Sunder and Prashar (2020) deficiency in communication and organisation belongs to the Critical Failure Factors of Continuous Improvement and key references.

The conclusion comes to mind that while Continuous Improvement is a strategic goal of many companies, the use of specific tools and practices related to it and the employees' empowerment are areas that require an in-depth work. The results show that quality management plays an important role in the surveyed companies, including focus on quality and on the customer. It can also be concluded that the application of CI at the operational level is an area where it is not yet fully implemented. In enterprises, CI offices or CI specialists are established, but their role in the development of the improvement processes seems to be still too small. Their tasks are undoubtedly crucial for the development of the CI concept, therefore their strengthening may have a significant impact on the effectiveness of the improvement activities. The results of the study indicate that both the application of the principles and values of CI and the key CI practices are areas that require support and development in order to live up to the challenges faced by manufacturing companies operating in Poland. They produce results relevant to practitioners, pointing out the weaknesses in the implementation of CI.

The limitation of the conducted research is the fact that it was conducted on a sample of 70 companies operating in Poland. Finally, a further direction for future research is to extend the research to a larger group of enterprises with a simultaneous analysis of their maturity level in order to develop detailed recommendations on the organization of a continuous improvement system in manufacturing enterprises.

REFERENCES

Alvarado-Ramírez, K.M., Pumisacho-Álvaro, V.H., Miguel-Davila, J.Á. and Suárez Barraza, M.F. (2018), 'Kaizen, a continuous improvement practice in organizations: A comparative study in companies from Mexico and Ecuador', *TQM Journal*, Emerald Group Holdings Ltd., Vol. 30 No. 4, pp. 255–268.

Anand, G., Ward, P.T., Tatikonda, M. V. and Schilling, D.A. (2009), 'Dynamic capabilities through continuous improvement infrastructure', *Journal of Operations Management*, No longer published by Elsevier, Vol. 27 No. 6, pp. 444–461.

Boer, H. and Gertsen, F. (2003), 'From continuous improvement to continuous innovation: A (retro)(per)spective', *International Journal of Technology Management*, Inderscience Publishers, Vol. 26 No. 8, pp. 805–827.

Butler, M., Szwejczewski, M. and Sweeney, M. (2018), 'A model of continuous improvement programme management', *Production Planning and Control*, Taylor & Francis, Vol. 29 No. 5, pp. 386–402.

Corso, M., Giacobbe, A., Martini, A. and Pellegrini, L. (2007), 'Tools and abilities for continuous improvement: What are the drivers of performance?', *International Journal of Technology Management*, Inderscience Publishers, Vol. 37 No. 3–4, pp. 348–365.

Dabhilkar, M., Bengtsson, L. and Bessant, J. (2007), 'Convergence or National Specificity? Testing the CI Maturity Model across Multiple Countries', *Creativity and Innovation Management*, John Wiley & Sons, Ltd, Vol. 16 No. 4, pp. 348–362.

Dahlgaard, J.J. and Dahlgaard-Park, S.M. (2006), 'Lean production, six sigma quality, TQM and company culture', *TQM Magazine*, Emerald Group Publishing Limited, Vol. 18 No. 3, pp. 263–281.

Fannon, S.R., Munive-Hernandez, J.E. and Campean, F. (2022), 'Mastering continuous improvement (CI): the roles and competences of mid-level management and their impact on the organisation's CI capability', *TQM Journal*, Emerald Group Holdings Ltd., Vol. 34 No. 1, pp. 102–124.

Fryer, K.J. and Ogden, S.M. (2014), 'Modelling continuous improvement maturity in the public sector: Key stages and indicators', *Total Quality Management and Business Excellence*, Vol. 25 No. 9, pp. 1039–1053.

Galeazzo, A., Furlan, A. and Vinelli, A. (2017), 'The organizational infrastructure of continuous improvement – an empirical analysis', *Operations Management Research*, Springer, Vol. 10 No. 1–2, pp. 33–46.

Jaca, C., Viles, E., Mateo, R. and Santos, J. (2012), 'Components of sustainable improvement systems: Theory and practice', *TQM Journal*, Emerald Group Publishing Limited, Vol. 24 No. 2, pp. 142–154.

Lameijer, B.A., Boer, H., Antony, J. and Does, R.J.M.M. (2021), 'Continuous improvement implementation models: a reconciliation and holistic metamodel', *Production Planning and Control*, Taylor & Francis, available at:https://doi.org/10.1080/09537287.2021.1974114.

McDermott, O., Antony, J., Sony, M. and Daly, S. (2022), 'Barriers and Enablers for Continuous Improvement Methodologies within the Irish Pharmaceutical Industry', *Processes*, Multidisciplinary Digital Publishing Institute, Vol. 10 No. 1, p. 73.

McLean, R.S., Antony, J. and Dahlgaard, J.J. (2017), 'Failure of Continuous Improvement initiatives in manufacturing environments: a systematic review of the evidence', *Total Quality Management and Business Excellence*, Vol. 28 No. 3–4, pp. 219–237.

Middel, R., Op De Weegh, S. and Gieskes, J. (2007), 'Continuous improvement in the Netherlands: A survey-based study into current practices', *International Journal of Technology Management*, Inderscience Publishers, Vol. 37 No. 3–4, pp. 259–271.

Moosa, K. and Sajid, A. (2010), 'Critical analysis of Six Sigma implementation', *Total Quality Management and Business Excellence*, Routledge , Vol. 21 No. 7, pp. 745–759.

Oprime, P.C., de Sousa Mendes, G.H. and Pimenta, M.L. (2011), 'Continuous improvement: Critical factors in Brazilian industrial companies', *International Journal of Productivity and Performance Management*, Emerald Group Publishing Limited, Vol. 61 No. 1, pp. 69–92.

Rodgers, B., Anthony, J. and Cudney, E.A. (2021), 'A critical evaluation of organizational readiness for continuous improvement within a UK public utility company', *Public Money and Management*, Routledge, available at:https://doi.org/10.1080/09540962.2020.1868127.

Sanchez, L. and Blanco, B. (2014), 'Three decades of continuous improvement', *Total Quality Management and Business Excellence*, Routledge, Vol. 25 No. 9–10, pp. 986–1001.

Singh, J. and Singh, H. (2015), 'Continuous improvement philosophy – literature review and directions', *Benchmarking*, Emerald Group Holdings Ltd., Vol. 22 No. 1, pp. 75–119.

Suárez-Barraza, M.F., Ramis-Pujol, J. and Kerbache, L. (2011), 'Thoughts on kaizen and its evolution: Three different perspectives and guiding principles', *International Journal of Lean Six Sigma*, Vol. 2 No. 4, pp. 288–308.

Sunder M., V. and Prashar, A. (2020), 'Empirical examination of critical failure factors of continuous improvement deployments: stage-wise results and a contingency theory perspective', *International Journal of Production Research*, Taylor & Francis, Vol. 58 No. 16, pp. 4894–4915.

Terziovski, M. and Power, D. (2007), 'Increasing ISO 9000 certification benefits: A continuous improvement approach', *International Journal of Quality and Reliability Management*, Emerald Group Publishing Limited, Vol. 24 No. 2, pp. 141–163.

Venkateswarlu, P. and Nilakant, V. (2005), 'Adoption and persistence of TQM programmes - Case studies of five New Zealand organizations', *Total Quality Management and Business Excellence*, Routledge , Vol. 16 No. 7, pp. 807–825.

Vinodh, S., Antony, J., Agrawal, R. and Douglas, J.A. (2021), 'Integration of continuous improvement strategies with Industry 4.0: a systematic review and agenda for further research', *TQM Journal*, Emerald Group Holdings Ltd., Vol. 33 No. 2, pp. 441–472.

Service Design: prospects and challenges on its adoption

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Purpose

Service Design emerges as a holistic, iterative, collaborative, and human-centered approach that aligns the customers, business, and other relevant stakeholders' needs. It is relevant to understand the reasons underlying its relatively scarce utilization, how to encourage a larger adoption of Service Design, and to anticipate the prospects of its future utilization.

Design/methodology/approach

To accomplish the aforementioned purpose, from a global perspective as well as from a country perspective, a Delphi analysis was promoted.

Findings

Experts predict a change of focus on Service Design, which will evolve from a customer-centered to a life-centered design approach. Furthermore, digitalization will be a driver for bringing customer experience to the development of services, mainly in the large B2B and B2C groups.

Service Design practices are rare in Portugal, and possibilities of further developments are discussed in this research.

Research limitations

The main limitation of the study was the difficulty in selecting experts to participate, namely due to the lack of people working in the field as well as their willingness to contribute. Nevertheless, after a significant effort, a reliable panel was achieved.

Originality/value

The effectiveness of Service Design is undisputable, taking into account its ability to keep pace with changes towards a "desirable future". This piece of research tries to anticipate this movement, stressing the trends that will shape the future of Service Design, thus contributing to outlining the most promising research streams in the field.

Keywords: Service Design, Customer experience, Co-Creation, Delphi Method

Paper type: Research Paper

INTRODUCTION

Current societies live in a context of major transformations in multiple domains driven by the rapid evolution of Information and Communication Technologies (Almeida & Pereira, 2014). The service sector is no exception and is increasingly reinventing itself through the development of new forms of service delivery and new business models. This largely results from the adoption of technology in this sector, as it is a process that influences the relationship between employees and customers (Almeida & Pereira, 2014).

The emergence of Information and Communication Technologies, promotes digital inclusion in society, boosting the democratization of access to technologies, one of the main factors responsible for the relationship of dependence between society and technology. Therefore, the presence of technology in social practices is noticeable, including in the way in which one thinks, acts, and relates.

Thus, new habits, new forms of communication, and new demands emerge. Former luxuries become necessities and consumers are progressively more connected, active, informed, and demanding in the selection of products and services and in the way in which they are delivered.

As a consequence, new interactions arise between consumers and companies that force organizations to rethink their corporate logic, to be more responsive to consumer experiences (Prahalad & Ramaswamy, 2002, 2004). With these changes, companies are obliged to question, evaluate and restructure their strategic approaches. Thus, each organization must seek to innovate all its sectors, mainly services, to understand customer needs and develop tools that allow empathy and ease of use in all types of communications with the customer. It’s important to rethink the approach and rewrite the exchange of value and trust between companies and customers, for organizations to be able to manage and respond to technological and social changes and, continuously and quickly, innovate to differentiate themselves and adapt to the customers' needs.

From this need, arises a discipline, called Service Design (SD), which allows organizations to innovate their services and develop new value propositions based on new technologies, the development of new markets, operational resources, on the systems they have available but, mainly, on the real needs of customers, (Stickdorn, Hormess, Lawrence, & Schneider, 2018). Service Design is therefore a holistic, iterative, collaborative, and human-centered discipline that uses a broad set of tools to create and orchestrate experiences that meet the needs of the business, the customer, and other stakeholders (Stickdorn et al. al., 2018).

It is essential to understand how Service Design fits the long-term needs of organizations and society, and how it is able to adapt, deal with and anticipate the disruptive changes in the world and create a "desirable future".

The main objective of this research is to investigate the long-term application of Service Design, namely, to analyze how this discipline can anticipate and deal with disruptive changes in the world and have a significant influence on a "desirable future". To fulfill the proposed objective, the following secondary objectives were defined: 1) identify the trends that are in the genesis of the adoption of SD in organizations; 2) explore Service Design's new scope and opportunities for action; 3) characterize the consumers and service designers of the future; 4) assess the need to restructure Service Design *(e.g. tools, guiding principles)* to ensure the adequacy of this discipline in the future; 5) identify the main challenges and obstacles to the adoption of Service Design in organizations; 6) evaluate how Service Design can be implemented in organizations and where its adoption will be most noticeable; 7) analyze the adoption of Service Design in Portugal and predict its future evolution.

Service Design

With a movement toward service-based economies, Service Design has become prominent in creating value for customers. The reason is the transition to a broader focus, which is no longer oriented simply to product aesthetics, but to understanding customer needs, focusing on value creation and the creation of experience-centric services. It's, therefore, a crucial discipline for the survival of companies in the economy marked by Service-Dominant Logic (Andreassen et al., 2016).

The Service Design has its origins in the design culture and is essentially focused on the interaction of the service with the consumer, through the service experience, interface, and identity (the visible part of the service through the which consumers interact and guide their behavior and decisions) (Maffei et al., 2005). Therefore, this discipline facilitates the development of value propositions through guiding principles and design tools that identify new possibilities for continuous value co-creation between the customer, organizations, and other stakeholders (Korper et al., 2020).

> Stickdorn, Hormess, Lawrence, & Schneider (2018) describe Service Design as a holistic, iterative, collaborative, and interdisciplinary human-centered discipline that uses a broad set of tools to create and orchestrate experiences that meet the needs of the business, customer, and other stakeholders. It is used to innovate or improve an existing service, making it usable and desirable to customers, while making it more efficient and effective for organizations that, through collaborative methods, can truly and completely understand their needs, developing holistic and meaningful solutions

(Moritz, 2005; Stickdorn et al., 2018).According to Stickdorn et al., (2018), there are six SD principles:

• Human-centered: One of the main objectives of Service Design is the full understanding of the customer's needs and expectations, through the familiarization of their individual needs, lifestyle, routine, background, or hobbies, to create a representation of their individuality, and identify their motivations and perceptions;

• Collaborative: Integrates stakeholders from different areas and functions in the Service Design process;

• Iterative: Until the service implementation phase, Service Design is an exploratory, adaptive and experimental discipline, which undergoes several iterations until reaching the right solution;

• Sequential: The service must be visualized and orchestrated as a sequence of interrelated actions;

• Real: The needs must be real and not presupposed, the ideas must be concrete and prototyped and the intangible values must be evidenced in physical or digital reality;

• Holistic: Service Design, as a multidisciplinary discipline, has to include and sustainably meet the needs of all those affected by the service, from the end customer to the needs of organizations, which includes all processes, systems, structure, values, and ethics. In this way, Service Design is the design of the overall experience of a service, as well as the design of the process and strategy underlying that service.

Through these six principles, Service Design combines the guiding principles of human-centered, collaborative, and aesthetic design with an interactive, multi-actor value creation process (Korper et al., 2020). In this way, it is possible to corroborate the fundamental role of the client in the design of services by adopting a Service Design discipline, but also the need to include considerations of a multi-actor, systemic and participatory nature (Korper et al., 2020).

Multiple Service Design practices are referenced in the literature. As an example, according to Aricò (2018), Morelli developed a methodological framework for Service Design based on the model developed by Pugh & Morley, which includes the following activities:

i. Context Analysis and Interpretation: Initial phase of the design process aimed to understand and discover the needs and desires of customers. At this stage, service designers use methods such as interviews to empathize with customers and interpret their needs;

ii. System development: Phase that comprises the development of service sketches and scenarios, where the planning of activities is represented, including its sequence, duration, and interaction;

iii. Representation techniques: Phase where the main features of the service are represented through prototypes.

Stickdorn, Hormess, Lawrence, & Schneider (2018), suggest four main activities of the Service Design process:

i. Research: The first step aims to understand the needs of users and their behavior in interacting with the service, through a set of essentially qualitative research methods, which define the “how” and “why” of the window of opportunity. Through user participation in the process, designers can design a new solution, or improve the existing solution, from a user-centered perspective;

ii. Ideation: The followoing activity, ideation, is equivalent to the “Define” phase in the Double Diamond model. It corresponds to the analysis and synthesis of the possibilities identified in the “Research” phase through the generation of a set of ideas;

iii. Prototyping: This phase aims to explore and assess how users interact and behave with a future experience of a particular service. The creation of prototypes allows the team of designers to identify important aspects of the newly created concepts, explore new alternatives and evaluate those that suit the needs of the business, always following an iteration logic;

iv. Implementation: The phase that goes beyond experimentation and testing, this is the phase that makes the prototype a reality.

The adoption of Service Design has been growing over the last years and numerous studies are currently being carried out regarding the applicability of this approach. This applicability is quite cross-sectional including scopes like the public service design approach in the age of digitalization (Trischler & Trischler, 2021), an approach to adapting clinical workflows (Braune et al., 2021), and is even recognized as an essential contributor to promoting capabilities in innovation processes in many institutions (Morelli, et al., 2021).

METHODOLOGY

The Delphi Method was the adopted methodology to conduct the research.

Delphi Method

The Delphi method emerged with the RAND Corporation in the 1950s within the scope of a military project, "Project Delphi", sponsored by the United States of America, to develop a technique capable of gathering the most reliable consensus among a group of experts through of individual and anonymous questionnaires (Dalkey & Helmer, 1963; Okoli & Pawlowski, 2004).

According to Skulmoski et al., (2007), Rowe and Wright characterized four characteristics of the Delphi method:

- Anonymous: the anonymity of the participants allows each expert to share their opinions impartially, without suffering pressure from the other elements of the group;
- Iterative: carrying out multiple rounds allows participants to review their views in light of the progress of the work developed up to the time of each round of questionnaires;
- Controlled feedback: feedback from participants is controlled by sharing each one's perspectives with all the individuals in the group, offering the possibility for each element to generate additional insights on the subject under study, as well as to rethink their position or clarify it better;
- Statistical aggregation of the group's answers: the statistical representation of the answers given by the group allows a quantitative analysis and interpretation of the data collected, offers the possibility to follow the process of creating consensus among the specialists, and also presents results in the form of reports or conclusions.

Thus, this is an iterative approach that, through controlled feedback, allows the convergence of opinions from multiple experts, creating a structured opinion focused on solving the problem under study (Hsu & Sandford, 2007).

Delphi Panel

The results generated through the application of this method are directly influenced by the group of individuals belonging to the Delphi panel, so their selection must be rigorous and respect a set of criteria that have to take into account the area of study and the aimed objectives (Hsu & Sandford, 2007).

Following Hsu & Sandford (2007) and Skulmoski et al., (2007) criteria, participants with the following criteria were considered eligible:

- Individuals with professional knowledge and experience related to the application of the SD;
- Individuals who can contribute useful information and who are willing to review their initial or previous opinions to reach consensus;
- Individuals who work in Portugal and are aware of the status of SD in Portugal;
- Individuals with a strong ability to express their ideas clearly and objectively in writing;
- Individuals with the ability, willingness, and availability to participate.

One of the main decisions when applying the Delphi method is the definition of the panel's size , that is not tabulated and is not consensually shared in the literature (Hsu & Sandford, 2007).

Some authors suggest the definition of the size of the Delphi panel must take into account the complexity of the study to be investigated, the range of expertise needed to address the problem, and the objectives of the study, as well as a heterogeneous panel, in order to ensure a representation of multiple spectrums,constituting a rich database for in-depth analysis and the possibility of identifying options that facilitate effective decision-making.

After several invitations, a panel was finally formed, including experts from different areas as shown in Table 1. It must be stressed that all the experts from the panel had more than five years of experience in the specific field of Service Design, having participated in several projects in the area.

Table 1 - Panel distribution by education field

ID Expert	Education Field
A	Human Resource and Project Management
B	Degree in Digital Arts and Master in Digital Experience Design
C	Master’s in Service Engineering and Management
D	Service and Innovation Design
E	Management

Delphi Rounds

This research considerer 3 Delphi rounds, evaluating the following domains:

I. Characterization of the participants: This section collected information on the knowledge and professional experience of each specialist in the field of Service Design, identifying the years of experience of each participant in the area and the number of innovation and service development projects focused on consumer experience in which they have already participated.

II. Main trends: This section analyzed the main trends that are in the genesis of the adoption of Service Design by organizations.

III. New scopes & action opportunities: This section identified the new scopes and opportunities for Service Design to operate by identifying areas where SD can have the most impact, understanding how SD will enable organizations to think about products and services differently and the characterization of the consumer and service designer of the future.

IV. Processes, Methodologies & Tools: This section assessed the need to restructure SD processes, methodologies and tools to meet the needs of the future. In this segment, the current limitations of Service Design were evaluated and how they impact its future use.

V. Service Design in organizations: This section evaluated how the SD can be adopted by organizations and analyzed the ability of this discipline to adapt to the cultural differences of organizations, employees, and customers.

VI. Public & Private Sectors: This section identified the main challenges/obstacles that public and private organizations face in the current context and the future impact of SD in strategic and operational terms of these two sectors.

VII. Ethics & Sustainability: This section evaluated the impact of SD on the phenomena of info exclusion and/or violation of customer privacy and its role as a tool to enhance the creation of future sustainable ways of life.

VIII. Service Design in Portugal - This section addressed the evolution of Service Design in Portugal and evaluated its current perception in the country.

The level of convergence was evaluated according to the scale represented in the Table 2.

Table 2 – Description of the convergence levels used in the analysis of the Delphi rounds responses

% level of convergence	Criteria	Description
20%	Absence of convergence	Analysis of the responses suggests 0 converging opinions
40%	Weak level of convergence	Analysis of the responses suggests 2 converging opinions
60%	Moderate level of convergence	Analysis of responses suggests 3 converging opinions
80%	Satisfactory level of convergence	Analysis of the responses suggests 4 converging opinions
100%	Total convergence	Analysis of the responses suggests 5 converging opinions

An acceptable level of convergence was considered when the analysis of the responses suggested a level equal to or greater than 80%.

RESULTS

Key Trends

Figure 1 presents the opinions expressed by the panel regarding the trends that lead to the adoption of Service Design in organizations.

The analysis at the level of convergence unanimously indicates digitalization as one of the main phenomena that boost the adoption of SD in organizations.

Digitalization arises from two perspectives: as a consequence of the discipline's focus on the customer, as it is a way of thinking about customer journeys from its origin, and, due to the acceleration of digitalization motivated by COVID-19, which forces organizations to adopt and provide increasingly digital services, not only for their customers but also for their employees.

The customer experience also appears as one of the main trends that will influence the SD adoption due to the growing need to develop effective and efficient services, based on user evidence to inform decisions within the organization itself and to develop solutions capable of responding to their problems.

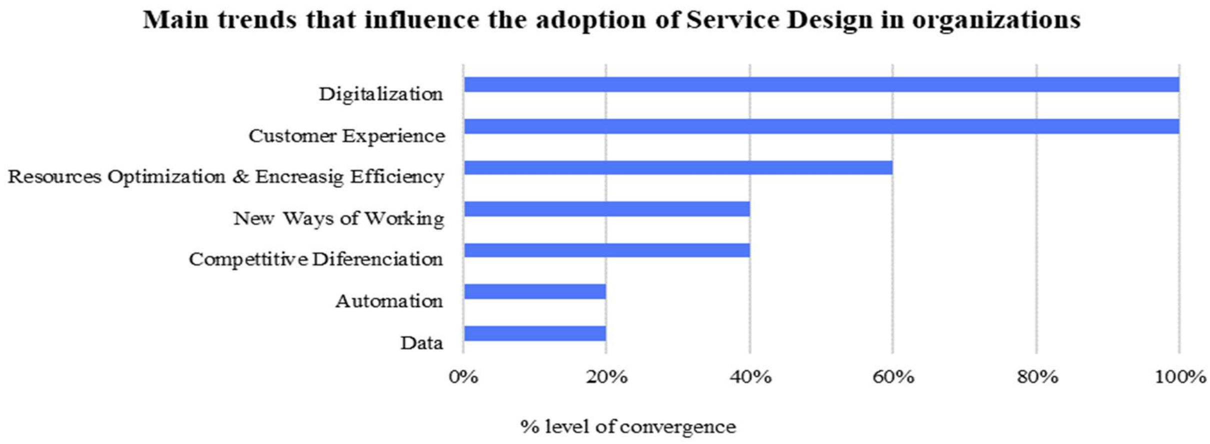

Figure 1 - panel response distribution to que question "What trends can lead to the adoption of Service Design in organizations?"

<u>New scopes and action opportunities</u>

The responses analysis unanimously suggests the existence of a wide range of opportunities for the SD to act due to its reduced footprint. Nevertheless, the opinions expressed indicate the public sector as a future area of action for the SD, as it is a sector that is not very digitalized and offers fundamental services for society, such as education, health, social security, and transport, among others.

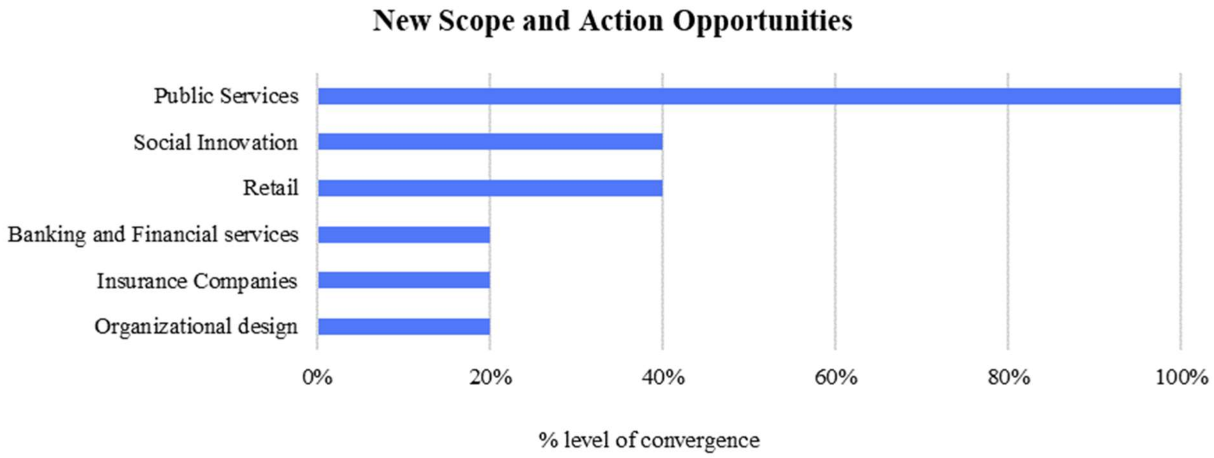

Figure 2 – Panel response distribution to the question "What are the new scopes and action opportunities for Service Design?"

However, experts also predict the adoption of Service Design in large B2B and B2C business groups, especially in highly competitive markets such as finance, due to their need to transform and follow the new needs of consumers well like those on the market.

The responses analysis suggested a 100% level of convergence regarding the description of the consumer of the future, which depends on a set of factors, such as social and educational, making it impossible to generalize a specific definition for all existing societies.

However, one opinion expressed that society will evolve towards a greater understanding of global phenomena, becoming more digital, demanding, and informed regardless of the factors underlying its surroundings (education, social environment, country).

Regarding the characterization of the Service Designer of the future, the panel was asked to rate on a scale from 1 to 3 (with 1 being slightly important and 3 being very important). It was also requested that no classification should be given to not relevant characteristics.

From the analysis of Figure 3, two very important characteristics (level 3) of the Service Designer of the future can be identified with 100% convergence: empathetic and facilitator. Additionally, it appears that four specialists - 80% of convergence - consider other two characteristics very important: communicator and rational.

Regarding the important characteristics (level 2), with a level of convergence of 80%, the following characteristics are pointed out: influencer, ability to visualize things that do not yet exist and willingness to help others.

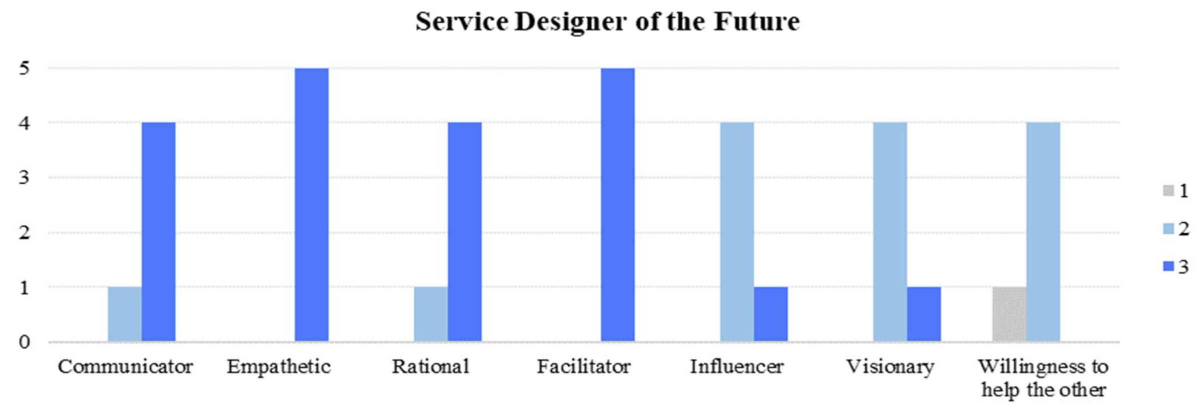

Figure 3 – Panel response distribution regarding the description of the Service Designer of the Future

Processes, methodologies and tools

The analysis of the first Delphi Round suggested a unanimous opinion regarding the lack of knowledge that currently exists about Service Design, which is its biggest limitation and the reason why it is still little recognized and adopted in Portugal. However, other limitations were identified, arising the need to iterate this question once more, asking the panel to select the options with which they most identified. Figure 4 illustrates the results obtained.

The multifaceted characteristic of Service Design stands out as another key limitation of its adoption, requiring time and trust, making it difficult to be accepted it in the governance of organizations and complex systems that are highly resistant to change.

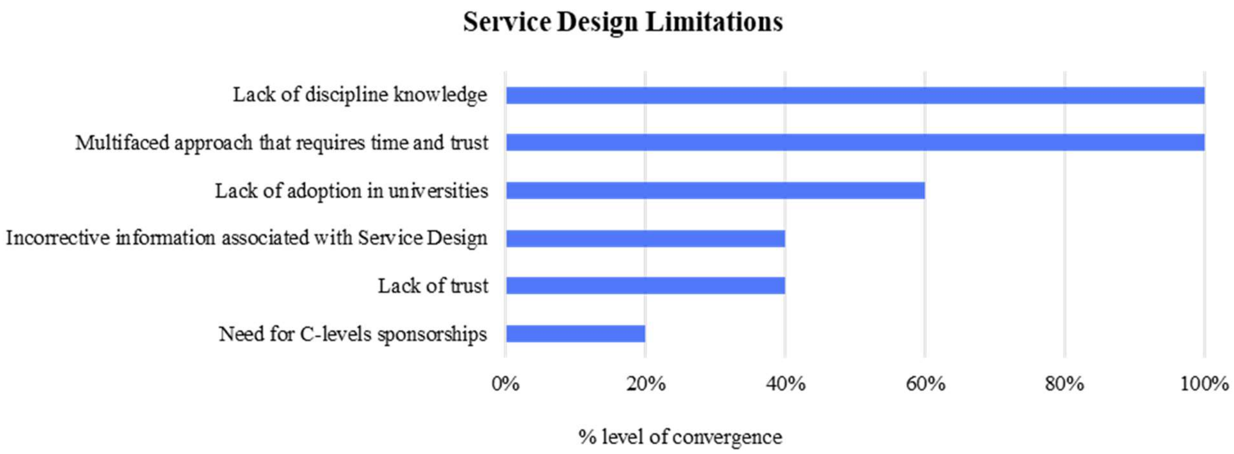

Figure 4 - panel response distributions regarding the question: "What are the main Service Design limitations?"

Service Design in organizations

Most of the responses to the first questionnaire showed that Service Design should be implemented in organizations through the creation of a small-scale area. However, divergent opinions emerged regarding the composition of that area. Thus, in a second iteration, the experts were asked to choose between the following two options:

- Option 1: Service Design must have its team within the company, made up of representatives from each silo of the organization and with an active role in decision making;
- Option 2: Service Design must have a team organized from small independent teams in each of the company's silos.

The obtained results revealed that 80% of the panel considers that the adoption of Service Design should come from an independent team, formed by representatives from each silo of the organization. This team will allow greater knowledge about each of the areas and a greater connection between all the silos.

Public and Private sector

The panel suggests two major Service Design limitations (Figure 5), namely the organizational culture of public and private companies, which in recent decades have focused on hierarchical decision-makers with a less collaborative mindset, not promoting fundamental changes in the existing work method and the lack of flexible, agile and adaptable employees.

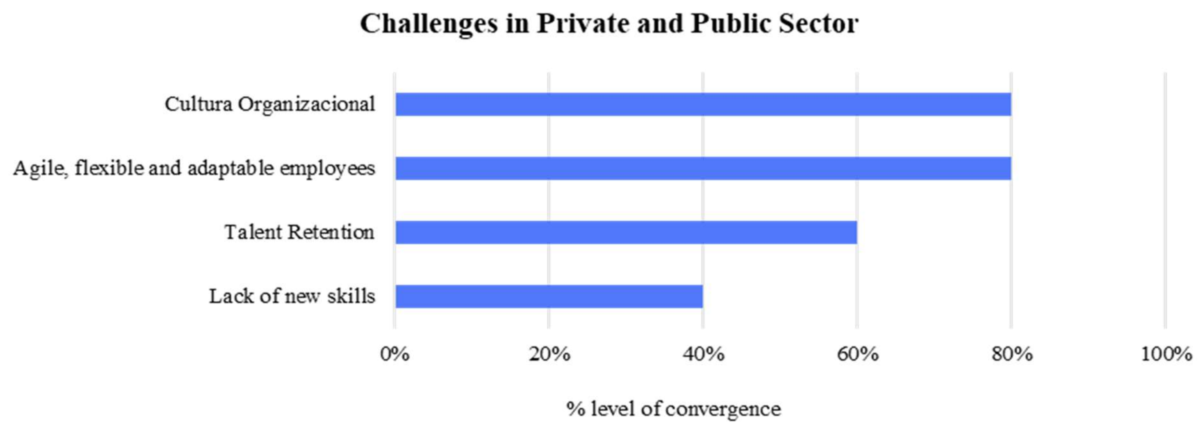

Figure 5 - Panel response distribution to the question "What are the main challenges that Public and Private organizations face in this current context?"

Ethics and Sustainability

According to the first round, it was consensual among specialists that Service Design should be applied to enhance the creation of future sustainable ways of life and that does not promote the info-exclusion phenomenon.

The panel also suggested that Service Design will increasingly deviate from its current user/client focus and will evolve towards an orientation that focuses on the human being in the society, adopting a life-centered design perspective. Thus, Service Design will position itself to co-create a desirable future in a way that goes beyond the people-centered and system focus but planet-centered, empowering the future creation of new sustainable ways of life.

Service Design in Portugal

The analysis of the first questionnaire showed a level of total agreement between the panel on the slow and gradual evolution of Service Design in Portugal, allowing the identification of a set of opinions regarding the way in which this discipline will be adopted in the country. In this sense, a survey of these assessments was carried out and they were presented to the panel in a second iteration, so that each expert could classify them on a scale from 1 to 3, with 1 being slightly important and 3 being very important. Figure 6 shows the obtained results.

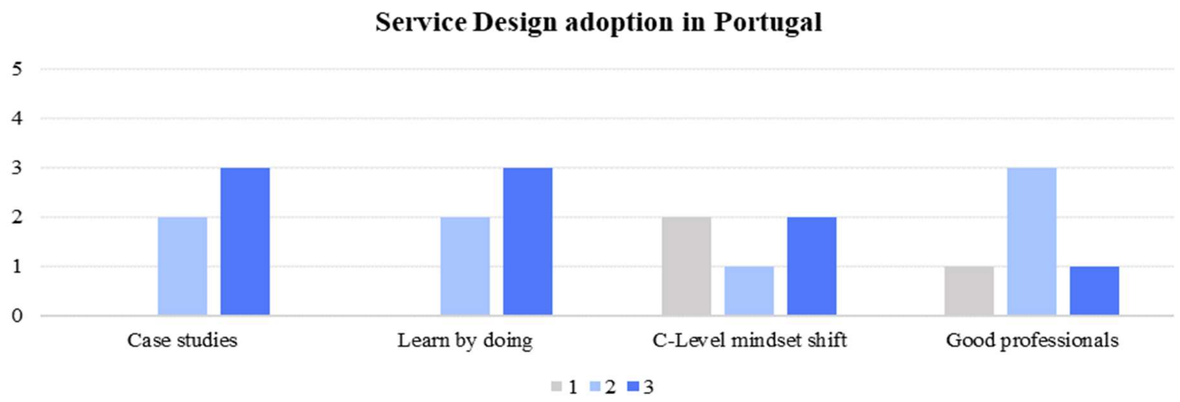

Figure 6 - Panel response distribution regarding the factors that will influence the Service Design adoption in Portugal

Figure 6 shows that none of the opinions expressed was scored with the same classification by the panel (for example, no opinion was considered level 3 among the 5 experts). However, two main factors that influence the adoption of this discipline in Portugal stood out, namely: the realization of case studies to promote the discipline and the adoption from a learn by doing perspective. 60% of the panel rates these factors at the highest level of importance (3) and 40% at level 2, generally suggesting that these are the main drivers for the adoption of this discipline in the future.

In the first iteration with the panel, multiple opinions highlighted the need to adopt the SD in the provision of higher education, namely in undergraduate and master's programs. In this sense, it became relevant to evaluate this issue in a second iteration, to measure the level of consensus among all experts. The analysis of the responses suggests a level of convergence of 100% between the panel in the integration of the discipline in the university programs.

Nevertheless, the answers express divergent opinions regarding the selection of the branches of knowledge where the SD should be taught.

DISCUSSION

As mentioned, the objective of Delphi Methods is to structure complex group opinions and to develop consensus on future developments among a set of experts participating on the panel. Therefore, what is at stake it is the consensus among the panel experts regarding the future evolution of Service Design, i.e., the trends that will shape the future of Service Design, according to the expert's panel.

It was not possible to achieve unanimity in all the analyzed questions, although some consensus emerged in several nuclear questions as presented in Table 3.

Table 3 – Key results of the study

Key Dimensions Under Study	Result	Conclusion
Service Design as a discipline that influences a "desirable future"	100%	Ability to respond to complex organizational problems systemically and holistically, having a significant influence on a "desirable future"
Service Design as a life centered approach	100%	Deviate from a user/client focus to evolve towards an orientation that focuses on the human being as a society - life-centered design perspective
Service Design adoption trends	100%	Digitalization and customer experience
Scope of action and opportunities	100%	Public services as an opportunity and BSB and B2C as a key prediction of major adoption
Future Consumer characteristics	100%	No general definition for all existing societies as it depends on a set of factors (e.g. social and educational)
Future Service Designer characteristics	100%	Empathetic and facilitator
Service Design limitations	100%	Lack of discipline knowledge and multifaceted approach that requires time and trust
Service Design adoption in organizations	80%	Service Design should come from an independent team, formed by representatives from each silo of the organization
Service Design challenges	80%	Organizational Culture and lack of agile, flexible and adaptable employees
Service Design in Portugal	100%	Slow and gradual evolution of Service Design in Portugal
Service Design as a discipline to deal and anticipate changes	100%	Discipline well positioned to deal with and anticipate the disruptive changes due to its participatory and inclusive nature

Although Table 3 synthetizes the main results, two main conclusions deserve to be stressed, taking into account its impact on society.

One is the potential utilization of Service Design in Public Services. This is already being a reality in specific contexts (e.g. Trischler & Trischler, 2021), and a slow movement towards this approache is being noticed in several countries.

Another pivotal observation is the move of Service Design towards a life centered approach. In fact, all the experts believe that a transition will be noticed from a user/client focus towards an orientation that focus on human-being as a society, the life-centered perspective.

CONCLUSIONS

The study allowed to conclude that Service Design is a discipline well positioned to deal with and anticipate the disruptive changes in the world due to its participatory and inclusive nature, and the ability to respond to complex organizational problems systemically and holistically, having a significant influence on a “desirable future”. Thus, SD can think of future visions, which, in addition to meeting customer needs, ensure the company's growth and respond to society's technological, economic, and ecological challenges.

Furthermore, the SD will increasingly deviate from its current user/client focus and will evolve towards an orientation that focuses on the human being as a society, adopting a life-centered design perspective. In other words, Service Design will increasingly position itself in a way that goes beyond the people-centered approach toward a planet-centered approach, empowering the future creation of new sustainable ways of life. As mentioned before, this is a pivotal conclusion, as the recent tragic developments regarding the war in Europe and the climate changes have been demonstrating.

The panel's forecast allows concluding that the adoption of SD in organizations will be influenced by the increasing digitalization and digitization and the need to incorporate the customer experience in the development of services. Digitization arises from two perspectives: as a consequence of the discipline's focus on the customer, as it is a way of thinking about customer journeys from its origin, and, due to the acceleration of digitalization motivated by COVID-19, which forces organizations to adopt and provide increasingly digital services, not only for their customers but also for their employees.

Experts predict the adoption of Service Design in large B2B and B2C business groups, especially in highly competitive markets such as finance, consumer goods, insurance, and consulting, due to their need to transform and follow the new needs of consumers. Furthermore, it’s worth stressing the movement towards Service Design approaches that are being gradually implemented in several public services, namely those focused on IT.

Despite the panel anticipates a slow and gradual evolution of the adoption of Service Design in Portugal, it believes that this discipline has a residual and little-recognized application due to the lack of knowledge and because it is a multifaceted discipline that requires time, investment, and trust, making it difficult to accept it in complex organizations that present great resistance to change.

Regarding how Service Design should be adopted by organizations, most of the panel expresses the need to create a specific Service Design team, made up of representatives from each silo and with an active role in decision-making, ensuring the existence of a point of facilitation and connection between all the company's silos.

There was consensus that the description of the consumer of the future depends on several factors, such as geography, and level of education, making it difficult to define the consumer of the future across different societies. The panel as a whole agrees that the existence of a single consumer description anticipates the existence of a single persona and states that the presented consumer description can generally apply to consumers in developed countries or with some purchasing power because in multiple countries the biggest concern continues to be access to basic needs.

However, one opinion was expressed that society will evolve towards a greater understanding of global phenomena, thus becoming more digital, demanding, and informed regardless of the factors underlying its surroundings (education, social environment, country). Regardless of the degree of change and the way it will manifest itself in different societies, the consumer will be more digital, informed, and demanding because, despite the factors that influence their motivations, the perspective of evolution is common to all. Thus, the description presented, with those specific characteristics, does not necessarily imply the existence of a persona and does not refer to consumers in developed countries or with any purchasing power.

Regarding the service designer of the future, multiple key characteristics are identified: empathetic, facilitator, communicator, rational, influencer, ability to visualize things that do not yet exist and the willingness to help others.

The need to integrate Service Design into undergraduate and master's programs was unanimous to create good professionals in the area, reduce the lack of knowledge that exists about the discipline and promote its adoption in organizations. Regarding the branch of knowledge where this integration should be done, it was not possible to draw any conclusion due to the level of divergence between the panel.

Research Limitations & Future Research Suggestions

The main limitation of the study was the difficulty in selecting and inviting experts to participate, namely due to:

• Lack of enough people in the field willing to participate in this type of study;

• Lack of availability from experts contacted: most experts contacted did not respond;

• Regardless a considerable effort was made to increase the size of the panel, the initial expectations of a panel of 6 to 8 people was impossible to achieve in a reasonable time frame.

On some questions there was a different understanding among the panel about the scope to be questioned, contributing to a low level of consensus and giving rise to the need for a new iteration.

Taking into account the conclusions obtained through the study, the following future works are suggested:

• Evolution of Service Design from a life-centered design perspective, to understand the impacts of its adoption on SD's guiding principles and understand its need for adoption in the face of human-centered design;

• Study the adoption of SD in a public sector company, be it education, health, or transport, to ascertain its impact on society and on the company itself, both in strategic and operational terms;

• How SD can be integrated into undergraduate and master's programs and the impacts of this integration on the adoption of this discipline in organizations.

REFERENCES

Almeida, M. do R., & Pereira, J. M. (2014). Marketing de Serviços (1ª Edição; Manuel Robalo, Ed.). Lisboa: Edições Sílabo, Lda.

Andreassen, T. W., Kristensson, P., Lervik-Olsen, L., Parasuraman, A., McColl-Kennedy, J. R., Edvardsson, B., & Colurcio, M. (2016). “Linking service design to value creation and service research”. Journal of Service Management, *27*(1), 21–29. https://doi.org/10.1108/JOSM-04-2015-0123

Aricò, M. (2018). “Service Design as a Transformative Force: Introduction and Adoption in an Organizational Context”. Copenhagen Business School.

Braune K, Boss K, Schmidt-Herzel J, Gajewska KA, Thieffry A, Schulze L, Posern B, Raile K (2021) Shaping Workflows in Digital and Remote Diabetes Care During the COVID-19 Pandemic via Service Design: Prospective, Longitudinal, Open-label Feasibility Trial. JMIR Mhealth Uhealth; 9(4):e 24374 ,https://doi.org/10.2196/24374

Dalkey, N., & Helmer, O. (1963). “An experimental apllication of Deplhi method to use of experts”, Management Science, Vol. 9, pp. 458–467.

Hsu, C.-C., & Sandford, B. A. (2007). “The Delphi Technique: Making Sense Of Consensus”, Practical

Assessment, Research & Evaluation, *12*(10), 55–56. https://doi.org/10.1080/02688867.1988.9726654

Jakob Trischler & Jessica Westman Trischler (2021). "Design for experience – a public service design approach in the age of digitalization", Public Management Review, DOI: 10.1080/14719037.2021.1899272

Korper, A. K., Patrício, L., Holmlid, S., & Witell, L. (2020), "Service design as an innovation approach in technology startups: a longitudinal multiple case study", Creativity and Innovation Management, *29*(2), 303–323. https://doi.org/10.1111/caim.12383

Loo, R. (2002), "The Delphi method: A powerful tool for strategic management", Policing, *25*(4), 762–769. https://doi.org/10.1108/13639510210450677

Maffei, S., Mager, B., & Sangiorgi, D. (2005), "Innovation Through Service Design: From Research and Theory to a Network of Practice. A users' driven perspective", Joining Forces Conference, September, 22–24. Retrieved from http://eprints.lancs.ac.uk/51896/

Moritz, S. (2005), "A Practical Access to Service Design", The Health Service Journal, *17*, 442–451. https://doi.org/10.1089/tmj.2010.0201

Okoli, C., & Pawlowski, S. D. (2004), "The Delphi method as a research tool: An example, design considerations and applications", Information and Management, *42*(1), 15–29. https://doi.org/10.1016/j.im.2003.11.002

Prahalad, C. K., & Ramaswamy, V. (2002), "The Co-Creation Connection", Strategy and Business, (27), 50–61.

Prahalad, C. K., & Ramaswamy, V. (2004), "Co-creation experiences: The next practice in value creation", Journal of Interactive Marketing, 18(3), 5–14. https://doi.org/10.1002/dir.20015

Morelli, Götzen. N., Simeone A., Luca (2021), Service Design Capabilities, Springer Series in Design and Innovation, 10, 1-89. https://doi.org/10.1007/978-3-030-56282-3

Skulmoski, G. J., Hartman, F. T., & Krahn, J. (2007), "The Delphi Method for Graduate Research", Journal of Information Technology Education, *6*, 1–21. https://doi.org/10.1007/3-540-47847-7_10

Stickdorn, M., Hormess, M., Lawrence, A., & Schneider, J. (2018), This is Service Design Doing, Canadá: O'Reilly Media, Inc.

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Quality 4.0: a bibliometric study and research agenda

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ABSTRACT

Purpose - Quality 4.0 is an emerging research issue regarding how to adopt quality management in digital era or otherwise, as the application of Industry 4.0 technologies (big data, machine learning, internet of things, among other) into quality field. Technology integration in some areas has been mapped, for example the integration of process mining, big data and data science in the digital quality management. Based on these transformations, it is important to recognize what has been researched in the Quality 4.0 domain.

Design/methodology/approach - To answer these questions, it was analysed 105 documents published on the Quality 4.0 domain until mid-April 2022 in academic journals according to Web of Sciences and Scopus databases. A bibliometric analysis covering citation, co-citation (of authors, journals, and documents) and co-word was applied. Graphical analysis using VOSviewer software enhances the investigation.

Findings - The study provides trends in the Quality 4.0 domain, mainly for the 2020-2021's period. The result presents the most influential journals, papers, and authors. Moreover, the results show what has been researched in the Quality 4.0 domain.

Practical implications - This study grants many starting points for researchers and practitioners and contributes to expanding the Quality 4.0 domain vision.

Originality/value - This paper use Science Mapping Analysis, a methodology still poorly applied on Quality 4.0 domain.

Keywords: Quality 4.0, Bibliometric study, Science mapping analysis, VOSviewer

Paper type: Research Paper

INTRODUCTION

Quality 4.0 is an emerging research issue, especially in the last few years. It is observed that the Quality 4.0 concept is ceasing to be only an addendum of industry 4.0 and acquiring its own knowledge structure. Despite being recent, research on Quality 4.0 has been growing year after year, especially in 2021 when there is an explosive growth in the number of documents with new themes and specific frameworks.

Zonnenshain and Kenett (2020) proposed a nine elements framework focused in practical topics based on the innovation elements of Industry 4.0. On the other side, Sader *et al.* (2019) suggested a theoretical framework for integrating Industry 4.0 and Total Quality Management (TQM) principles according to ISO 9001:2015. Jacob (2017) recommended a model already used by Alzahrani *et al.* (2021) to assess higher education readiness for Quality 4.0 based on the literature. Other framework was proposed by Kumar *et al*., 2021.

With the growing interest in the subject, there is a need to know more about research in the Quality 4.0 domain. The present study seeks to contribute to create useful knowledge for the development of this research. The aim of this article is to answer the following research questions:

RQ1. Which are the most relevant authors, journals and documents related to Quality 4.0?

RQ2. Which are the most relevant authors journals and documents networks related to Quality 4.0?

RQ3. What has been researched in the Quality 4.0 domain?

To answer these questions, it was analysed 105 documents published on the Quality 4.0 domain until mid-April 2022 in academic journals according to Web of Sciences and Scopus databases. A bibliometric analysis covering citation, co-citation (of authors, journals, and documents) and co-word was applied. Graphical analysis using VOSviewer software enhances the investigation. These techniques have not been previously used in the Quality 4.0 field, so their application is a novel contribution. This study grants many starting points for researchers and practitioners and contributes to expanding the Quality 4.0 domain vision.

To assure the objectivity of this science mapping study, it was used the 5-steps procedure according to Zupic and Čater (2015) (Figure 1).

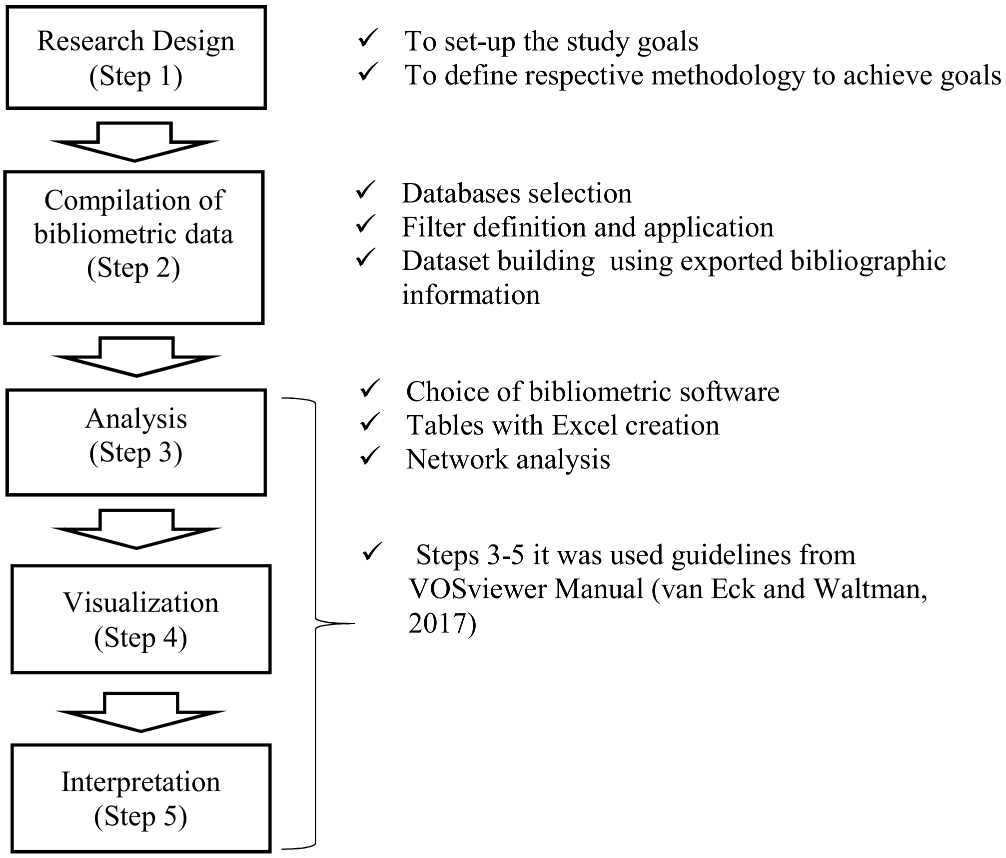

Figure 1 – Science mapping study 5-steps procedure according to Zupic and Čater (2015)

In the step 1 (Research Design) it was defined the study goal: to recognize what has been researched in the Quality 4.0 domain. To achieve this goal, it was also defined the bibliometric techniques to be applied: citation, co-citation (of authors, journals, and articles) and co-word was applied. Graphical analysis using VOSviewer software enhances the investigation.

In the step 2 (Compilation of bibliometric data) aiming to achieve a more comprehensive review (Gonzalez and van Aken, 2017), the option was made to use two databases: Web of Sciences (Clarivate Anaytics, 2018) and Scopus. A systematic search was conducted until the first half of April 2022 using the following keywords or descriptors: “Quality 4.0” and “Quality in Industry 4.0”. All kinds of documents written in English were considered, including research articles, proceedings papers and books. Each of the 105 documents was checked based on title and abstract screening to exclude those that were not related to Quality 4.0. At the end, 86 documents were approved and 15 were excluded. Some of the exclusion motives were documents that only mentioned Quality 4.0 and documents that brought 4.0 inside parentheses after the term quality, the latter being typical from the health area.

In the step 3 (Anaysis) it was choose Excel to create graphs and tables and VOSviewer software (Van Eck and Waltman, 2010) to realize all the network analysis. The decision for these software tools was motivated mainly for the possibility of use of two different databases: Web of Science (WoS) and

Scopus. Further, the Excel and VOSviewer combination allowed us to merge data from both databases. Aiming to improve results consistency it was disambiguated the names of authors, journals, and keywords, and it was avoided duplications.

In the Step 4 (Visualization) and Step 5 (Interpretation) it was followed guidelines from Van Eck and Waltman (2010). In particular, it was used the overlay visualization VOSviewer feature as a way to clarify keywords related to the 2020-2021's period. The outcomes of these two steps are part of the results of the present article. It was also considered the application described in some studies that use the same software combination (see, e.g., Niñerola *et al.*, 2021).

RESULTS

Exploratory data analysis

The descriptive analysis of 105 documents published on the Quality 4.0 domain until mid-April 2022 shows some important trends (Figure 2). It is possible to observe a clearly positive trend in the number of publication since 2018, highlighting the year 2021.

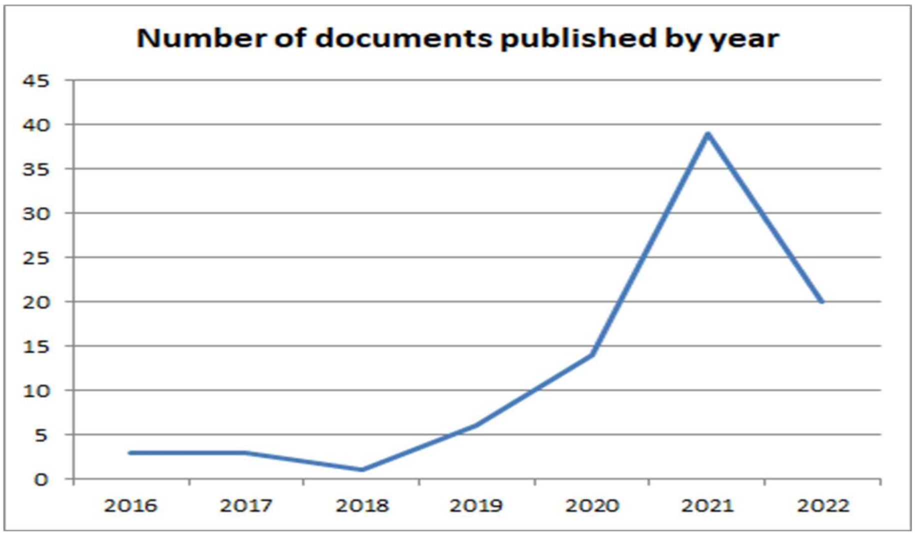

Figure 2 - Publishing trend - Data up to mid-April 2022.

Citation

Citation was used to measure the influence of a journal, author, or article.

Table 1 indicates the top 19 most cited and fruitful authors. This table includes only authors with, at least, 1 document and 11 citations. For example, 5 authors published 4 documents related to Quality 4.0: Antony, J.; Sony M.; Escobar, C.A.; Morales-Menedez, R. and Nenadái, J., and Antony, J. and Sony, M. are the two most cited ones.

Table 1. Top 19 most cited and fruitful authors.

Authors	Documents	Citations
1. Antony, J.	4	52
2. Sony, M.	4	52
3. Kenett R. S.	1	51
4. Zonnenshain A.	1	51
5. Chiarini A.	2	49
6. Haleem A.	3	14
7. Javaid M.	3	14
8. Suman R.	2	14
9. Jassbi J.	1	14
10. Ramezani, J.	1	14
11. Pratap Singh R.	1	13
12. Douglas, J.A.	1	50
13. Daróczi M.	1	22
14. Escobar, C.A.	4	16
15. Husti, I.	2	28
16. McGovern, M.E.	2	14
17. Morales-Menedez, R.	4	16
18. Nenadái, J.	4	31
19. Sader, S.	2	28

Searching in Scopus and WoS databases, it was identified 42 sources with at least one Quality 4.0 published document (including 30 journals and 12 conference proceedings). Table 2 shows the top 10 most cited journals. The main source of Quality 4.0 publications is The TQM Journal. Quality Engineering, Sustainability and Quality Innovation Prosperity show the next highest citation numbers.

Table 2 - Top 10 most cited journals.

Source title	Citations	Papers
1. The TQM Journal	126	9
2. Quality Engineering	51	1
3. Sustainability	51	5
4. Quality Innovation Prosperity	34	3
5. Periodica Polytechnica Social and Management Sciences	22	1
6. Journal of Intelligent Manufacturing	14	1
7. Processes	14	1
8. Sensors International	13	1
9. Springer, Charm	12	6
10. International Journal of Quality and Service Sciences	10	1

Table 3 shows the top 21 most cited documents in which Quality 4.0 is the central subject.

Table 3 - Top 21 most cited Quality 4.0 documents.

Documents	Citations
1. Zonnenshain and Kenett, 2020	51
2. Sony *et al.,* 2020	50
3. Chiarini, 2020	46
4. Fonseca *et al.* 2021	30
5. Nenadái, 2020	28
6. Sader *et al*., 2019	22
7. Escobar *et al*., 2021	14
8. Ramezani and Jassbi, 2020	14
9. Javaid *et al*., 2021	13
10. Emblemsvåg, 2020	12
11. Schönreiter, 2016	10
12. Sony *et al*., 2021	10
13. Yadav *et al*., 2021	10
14. Carvalho *et al*., 2021	10
15. Santos *et al.,* 2021	9
16. Alzahrani *et al*., 2021	9
17. Glogovac *et al*., 2020	9
18. Ngo and Schmitt, 2016	8
19. Sader *et al.,* 2021	6
20. Sütőová *et al*., 2020	6
21. Lim, 2019	6

This section answers RQ1: Which are the most relevant authors, journals, and documents related to Quality 4.0?

Co-citation

Contributions of authors often co-cited are expected to relate similar concepts. The most usual co-citation networks are author, journal, and document co-citation analysis (Nerur *et al.*, 2008). In this research, it was conducted this three co-citation analysis: (1) author co-citation analysis (Figure 3 and 4 and Table 4); document co-citation analysis (Figure 5 and Table 5); and journal co-citation analysis (Figure 6 and Table 6). In all these 3 analyses it was seeking to strike a balance of readability and completeness.

For author co-citation, it was considered an image with 34 from 6.509 authors (including references authors) with at least 15 citations allows visualization of four clusters (Figure 3).

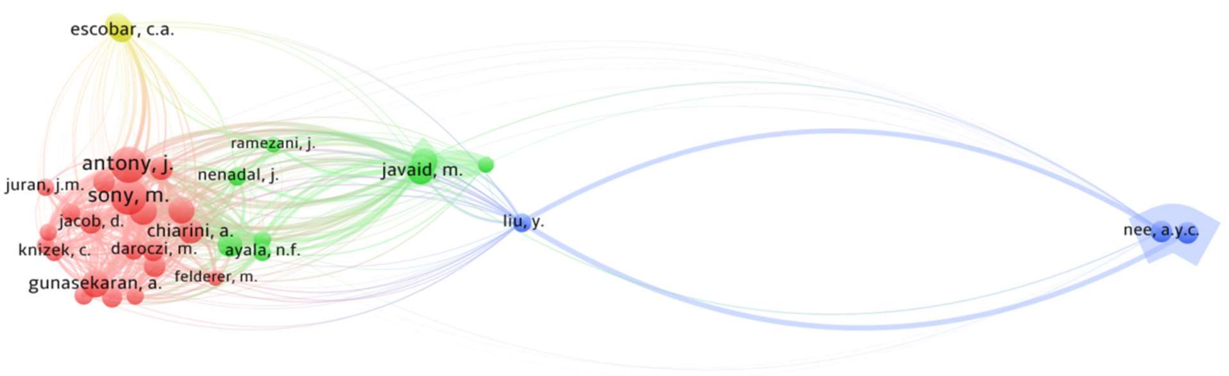

Figure 3 - Author co-citation analysis.

The authors of each one of 4 clusters are shown in Table 4.

Table 4 - Authors of each co-citation clusters.

Clusters (Number of authors)	Authors
#1 Red (21)	Antony, J.; Chiarini, A; Daroczi, M.; Douglas, J.A.; Felderer, M.; Gunasekaran, A.; Husti, I.; Jacob, D.; Juran, J.M.; Kagermann, H.; Kenett, R.S.; Knizec C.; Kupper, D.; Ngai, W.T.E.; Radziwill, N.; Ryeson, D.; Sader, S.; Sampaio, P.; Sony, M.; Subramanian, N.; Zonnenshain, A.
#2 Green (8)	Ayala, N.F.; Bahl, S.; Frank, A.G.; Haleem, A.; Javaid, M.; Nenadai, J.; Ramezani, J. Santos, G.
#3 Blue (3)	Liu, Y.; Nee, A.Y.C.; Ong, S.K.
#4 Amber (2)	Escobar, C.A.; Morales-Manendez, R.

For a better author and links visualization within the #1 cluster, it was chosen a detailed image (Figure 4).

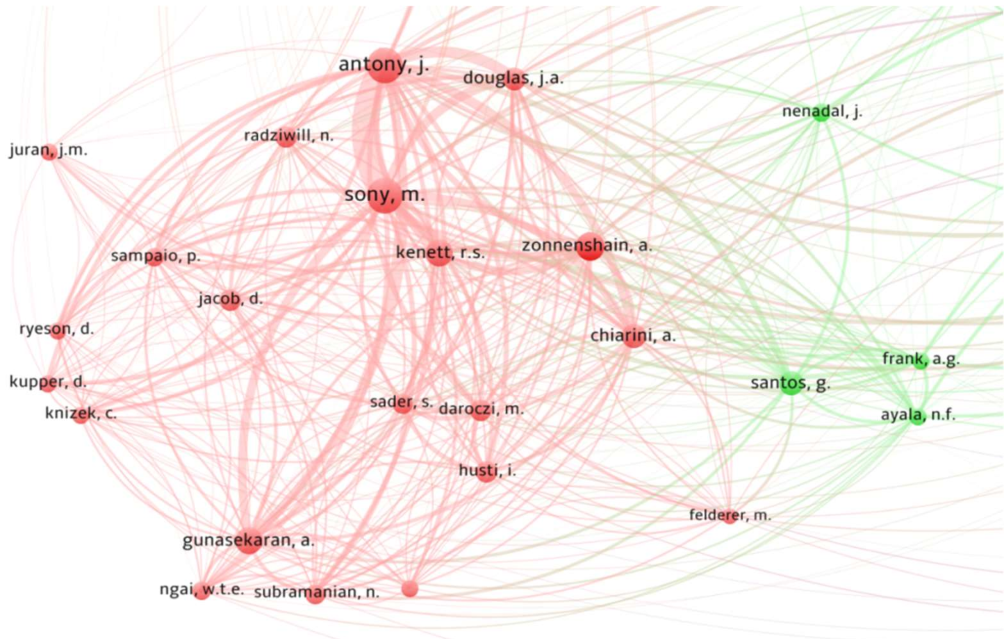

Figure 4 - Detailed view on #1 cluster authors and its links.

It is observable that Antony, J. and Sony, M. are the two most influential authors within #1 cluster.

For document co-citation it was chosen an image with 47 from 3.919 documents (including references) with at least 3 citations allows visualization of three clusters also seeking to obtain the balance of readability and completeness (Figure 5).

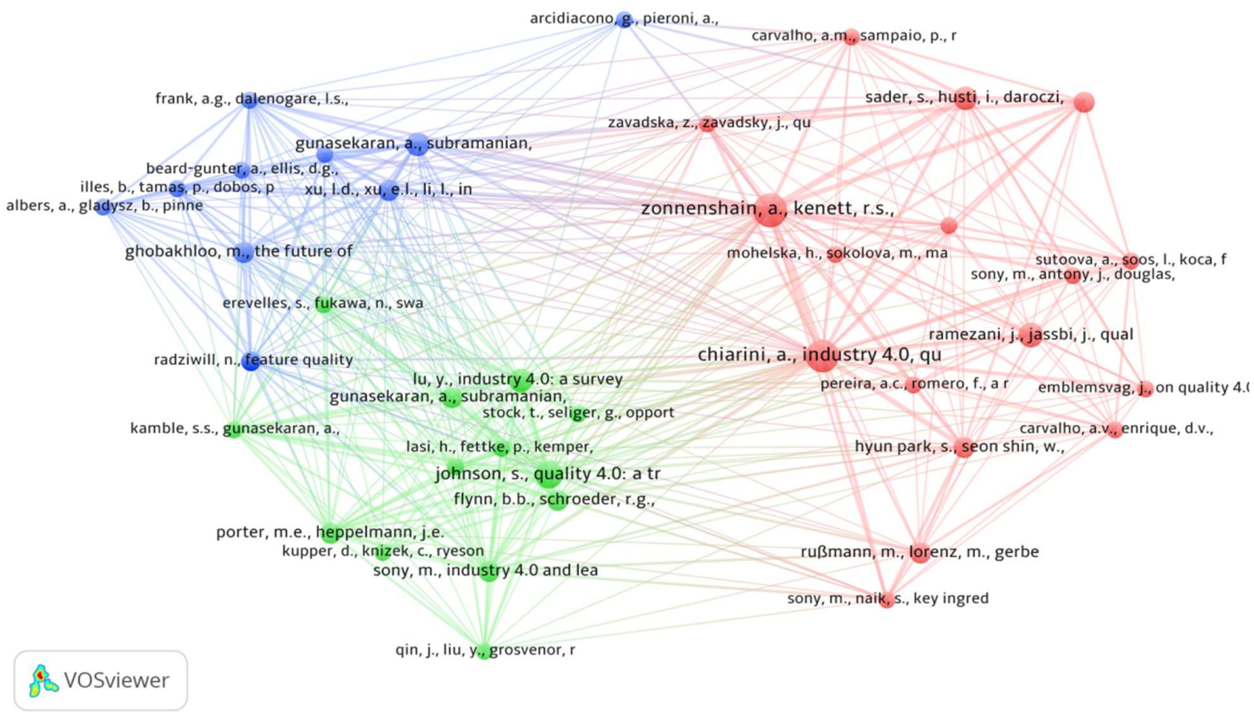

Figure 5 - Document co-citation analysis.

It is observable that Zonnenshain and Kenett (2020), Chiarini (2020) are the two most influential studies within #1 cluster; while Johnson (2019) and Gunasekaran and Subramarian (2019) are the main studies of each of #2 and #3 cluster, respectively.

The documents of each one of 3 clusters are show in Table 5. It was decided to subdivide the content of Table 5 for distinguish the co-cited document into two groups, according to the process that allow their identification.

Table 5 - Documents of each co-citation clusters.

Clusters (Number of documents)	#1 Document Group	#2 Document Group
	Co-cited documents found in original search of the present study (Step 2, Figure 1)	Co-cited documents identified for document co-citation analysis
#1 Red (17)	Carvalho *et al*. (2020); Chiarini A. (2020); Emblemsvåg, J. (2020); Kannan and Garad (2020); Nenadál, J. (2020); Ramezani and Jassbi (2020); Rüßmann *et al*. (2015); Sader *et al*., (2019); Sony *et al.* (2020); Sütőová *et al.,* (2020); Zonnenshain and Kenett (2020).	Carvalho *et at.* (2021); Hyun Park *et al*. (2017); Mohelska and Sokolova (2018); Pereira and Romero (2017); Sony and Naik (2019); Zavadska and Zavadski (2020)
#2 Green (13)	-	Erevelles *et al.* (2016); Flyn *et al.,* (1995); Gimenez Espin *et al.* (2013);

		Gunasekaran *et al*. (2019); Johnson (2019); Kamble *et al.* (2018); Kupper *et al*. (2019); Lasi *et al*. (2014); Lu Y. (2017); Porter and Heppelman (2014); Qin *et al*. (2016); Sony (2018); Stock and Seliger (2016);
#3 Blue (10)	Gunasekaran and Subramarian (2019	Albers *et al.* (2016); Arcidiacono and Pieroni (2018); Beard-Gunter and Ellis (2019); Frank and Dalenogare (2019); Ghobakhloo (2018); Illes *et al*. (2017); Radziwill (2018); Wang et al. (2016); Xu *et al*. 2018).

It was understood that the original search done in the Step 2 of the present study was able to found more than half of the co-cited documents for #1 cluster. On the other hand, the procedure missed all co-cited references from #2 cluster and almost all from #3 cluster. This finding confirms the document co-citation analysis importance and its contribution to realize a scientifically directed expansion of the study sample.

For journal co-citation it was chosen an image with 15 from 2.180 journals (including references) with at least 20 citations allows visualization of three clusters, always seeking to obtain the balance of readability and completeness (Figure 6).

Figure 6 - Journal co-citation analysis.

It is observable that The TQM Journal is the most influential journal. Journals closer concerning interest areas show higher co-citations and link strengths. (Niñerola *et al*. 2021).

The journals of each one of two clusters are show in Table 6.

Table 6 - Journal of each co-citation clusters.

Clusters (Number of Journals)	Journals
#1 Red (10)	Benchmarking: an International Journal; Computers in Industry; International Journal of Production Economics; International Journal of Production Research; International Journal of Quality and Reliability Management; Quality Engineering; Quality Progress; Sustainability; The TQM Journal; Total Quality Management & Business Excellence;
#2 Green (3)	International Journal of Advanced Manufacture Technology; Procedia CIRP; Procedia Manufacturing

This section answers RQ2. Which are the most relevant author, journal and document networks related to Quality 4.0?

Co-word

The research field conceptual structure can be examined by conducting a type of content analysis that uses words that form the titles, abstracts, and keywords of the articles (Callon *et al*., 1991). The top 22 most frequently co-occurring keywords of our dataset are shown in the Table 7.

Table 7 - Top 22 most frequently co-occurring keywords.

Keyword	Occurrences	Total Link Strength
1. quality 4.0	56	527
2. industry 4.0	43	392
3. quality management	22	219
4. quality control	13	177
5. artificial intelligence	7	111
6. big data	8	108
7. internet of things	6	101
8. design/methodology/approach	6	93
9. information management	5	78
10. machine learning	7	77
11. smart manufacturing	4	62
12. image analysis	2	61
13. process monitoring	3	60
14. competition	4	55
15. literature review	4	55
16. manufacture	3	51
17. quality assurance	4	51
18. manufacturing industries	3	50
19. industrial research	3	49
20. quality management system	3	49
21. decision making	4	47
22. managing quality	3	45

Note: after managing quality (keyword numbered as 22), other keywords have only a single occurrence in the document sample.

In the Figure 7 the node size designate their incidence. Smaller distances show strong relationships. The more dense the line, the more frequent the word co-occurrence (van Eck and Waltman, 2017).

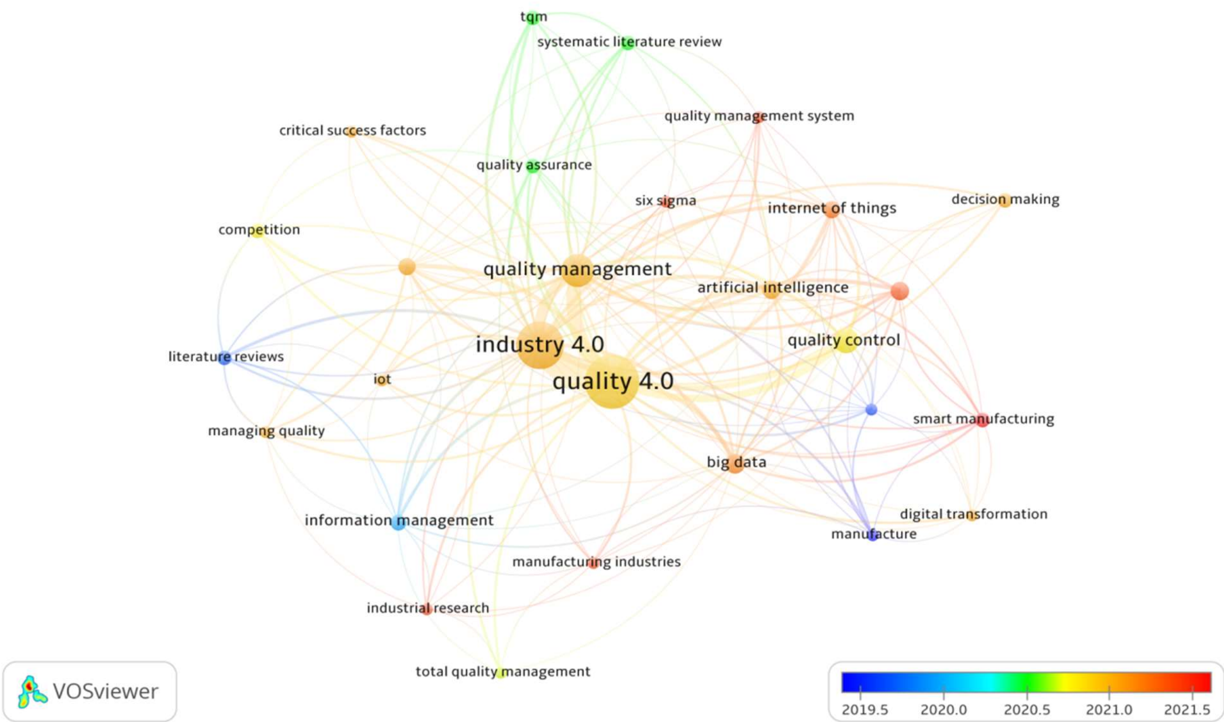

Figure 7 – Co-occurrence analysis of keywords (that appear in at least 3 documents)

The present dataset contains 506 keywords (including references keywords). To improve readability, it was selected only the top 28 (Figure 8). Consequently, each keyword has to appear at least in 3 papers.

As expected, the big node, that mean the most frequently word is quality 4.0, followed by "industry 4.0", "quality management", and so on, according to Table 7.

Trends in the Quality 4.0 domain based on co-word study

In-depth understanding of trends in any domain of knowledge requires carrying out a systematic review of the literature. Meantime, the findings from co-word study (Figure 7) allow glimpsing some Quality 4.0 recent research streams in a given sample of documents. Note that VOSviewer software, through a colour legend, makes it possible to distinguish the keywords most frequently associated with different periods (semesters) in which the studies were published. In this way, it is notorious that literature review, information management and manufacture (blue colour in Figure 7) are typical keywords until the first half of 2020. Similarly, tqm, systematic literature review, quality assurance (green colour) are associated to mid-year 2020. On the other way, it is observed a keyword set ranging from orange to red colour associated with the year 2021.

But, to get a clearer view of the most recently researched topics, a improved image was necessary. To clearly visualize the typical keywords for each most recent years, it was chosen to replace the automatic timescale provided by the VOSviewer software (2019.5-2021.5, as shown in Figure 7) with a shorter and more recent period (since 2020.0). This case, it was selected all the recurrent keywords (each keyword has to appear at least in 2 papers) (Figure 8).

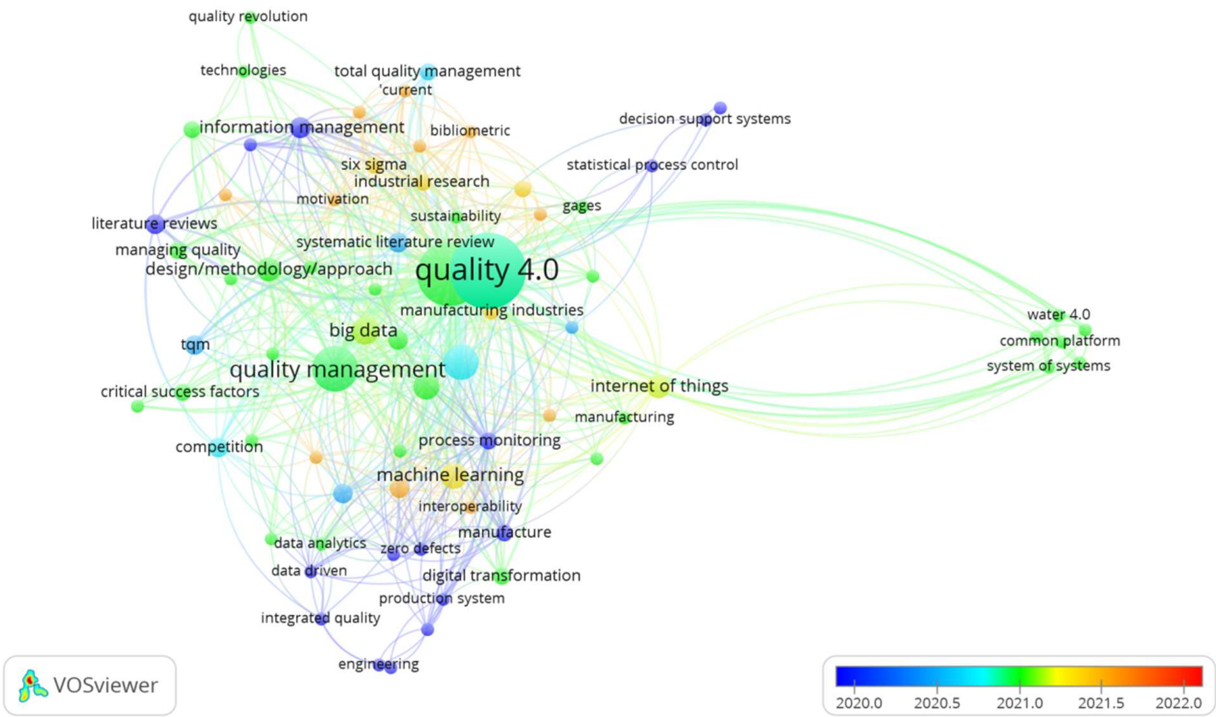

Figure 8 – Co-occurrence analysis of keywords (that appear in at least 2 documents)

From the complete visualization of all recurrent keywords, it was necessary to exam the whole 3 dimension networks provided by VOSviewer. In doing so, it was chosen to segregate the keywords for the document sample of this study for each of the periods (indicated in Figure 8) to ensure clarity of information regarding typically more recent keywords.

As this exam covers a large number (73) of recurring keywords and, at the same time, it is useful to know which cluster they belong to, it was decided to divide the presentation of the temporality results of the keywords by cluster in different tables: Table 8 for cluster#1, and so on, up to Table 12 for cluster # 5 to #8. Those five tables summarize the entire set of recurring Quality 4.0 keywords in the document sample of this study and place each one of them in time.

Table 8 - Temporality of recurring keywords belonging to cluster#1.

Keyword	2020.0	2020.5	2021.0	2021.5	2022.0
1. competition		x			
2. data analytics			x		
3. data driven	x				
4. engineering	x				
5. fourth industrial revolution			x		
6. industrial revolutions			x		
7. integrated quality	x				
8. interoperability				x	
9. management	x				
10. predictive analytics				x	
11. problem solving	x				
12. production system	x				
13. quality assurance		x			
14. zero defect	x				
15. zero defect manufacture	x				

Table 9 - Temporality of recurring keywords belonging to cluster#2.

Keyword	2020.0	2020.5	2021.0	2021.5	2022.0
1. artificial intelligence			x		
2. big data			x		
3. digital transformation			x		
4. employment			x		
5. engineering education			x		
6. machine learning				x	
7. manufacture	x				
8. predictive quality				x	
9. process monitoring	x				
10. quality control		x			
11. quality standard			x		
12. smart manufacturing				x	
13. sustainability			x		

Table 10 - Temporality of recurring keywords belonging to cluster#3.

Keyword	2020.0	2020.5	2021.0	2021.5	2022.0
1. design/methodology/approach			x		
2. iot			x		
3. literature reviews	x				
4. managing quality			x		
5. personnel			x		
6. quality improvement				x	
7. quality revolution			x		
8. six sigma				x	
9. technologies			x		

Table 11 - Temporality of recurring keywords belonging to cluster#4.

Keyword	2020.0	2020.5	2021.0	2021.5	2022.0
1. current				x	
2. bibliometric				x	
3. digitalization				x	
4. enterprise resource planning	x				
5. human resource management				x	
6. industrial research				x	
7. information management	x				
8. manufacturing industries				x	
9. motivation				x	
10. total quality management		x			

Table 12 - Temporality of recurring keywords belonging to cluster#5 to 8.

Keyword	2020.0	2020.5	2021.0	2021.5	2022.0
1. common plataform			x		
2. food processing			x		
3. internet of things			x		
4. multiple variants			x		
5. system of systems			x		
6. water 4.0			x		
7. water treatment			x		
8. defect detection			x		
9. manufacturing			x		
10. quality management			x		
11. quality management system				x	
12. systematic literature review		x			
13. decision support systems	x				
14. gages			x		
15. image analysis	x				
16. scanning	x				
17. statistical process control	x				
18. critical success factors			x		
19. lean six sigma			x		
20. tqm		x			

Note: Cluster#5 is composed by keywords numbered from 1 to 7 in this table; Cluster#6: from 8 to 12; Cluster#7: from 13 to 17; Cluster#8: from 18 to 20.

These tables allow the researchers to know how recent each topic is without having to redo the mapping using VOSviewer software, as was done in this study.

Finally, it was observed from the content of these table set (from Table 8 to Table 12) that:

- the VOSviewer did not assign any keyword to the year 2022 since we are in the first months of the year;
- the more recent Quality 4.0 keywords, associated with 2021.5 (orange colour) are: interoperability; predictive analytics, machine learning; predictive quality; smart manufacturing; quality improvement; six sigma; digitalization, human resource management; industrial research; manufacturing industries; motivation; quality management system.

However, it cannot be said that the other themes are obsolete, especially regarding to themes associated with column 2021.0 (green colour on Tables 8 to 12, and in the Figure 8).

This section answers RQ3. What has been researched in the Quality 4.0 domain?

DISCUSSION AND CONCLUSIONS

It was performed a bibliometric analysis with publications visualization on Quality 4.0 with the purpose of answering the following three research questions:

RQ1. Which are the most relevant authors, journals, and documents related to Quality 4.0?

RQ2. Which are the most relevant authors journals, and documents networks related to Quality 4.0?

RQ3. What has been researched in the Quality 4.0 domain?

The study revealed Antony, J.; Sony M.; Escobar, C.A.; Morales-Menedez, R. and Nenadái, J. as more fruitful authors and Antony, J. and Sony, M. as the two most cited ones. The top 19 most cited and fruitful authors are presented in the Table 1.

It was identified 42 sources with at least one Quality 4.0 published document (including 30 journals and 12 conference proceedings). The main source of Quality 4.0 publications is The TQM Journal. Quality Engineering, Sustainability and Quality Innovation Prosperity show the next highest citation numbers. The top 10 most cited journals are presented in the Table 2.

Moreover, it was identified the top 21 most cited documents in which Quality 4.0 is the central subject, as shown in Table 3.

To identify the most relevant author, journal and document networks it was also conducted three co-citation analysis: (1) author co-citation analysis (Figure 3 and 4 and Table 4); document co-citation analysis (Figure 5 and Table 5); and journal co-citation analysis (Figure 6 and Table 6).

Aiming to discover what has been researched in the Quality 4.0 domain, it was performed a detail co-word study using a poorly applied VOSviewer feature: the overlay visualization. In doing so, it was showed trends in the Quality 4.0 especially in the 2020-2021's period (Figure 8 and Tables from 8 to 12), segregated by clusters.

An important finding was the Quality 4.0 keyword set associated with the most recent period within the reach of a bibliometric study currently: 2021.5. This keyword set encompass: interoperability; predictive analytics, machine learning; predictive quality; smart manufacturing; quality improvement; six sigma; digitalization, human resource management; industrial research; manufacturing industries; motivation; quality management system. Another significant keyword set refers to the column 2021.0 (green colour in Tables 8 to 12, and in the Figure 8). These two keyword set can be considered what has been researched in the Quality 4.0 domain recently.

Limitations and Future directions of Quality 4.0

This study has some limitation that should be mentioned. Firstly, the authors used only bibliometric techniques and a relatively small sample of articles. As the research develops over the coming months and years, it will be possible to obtain a richer picture. Second, it was used only two databases: the WoS and Scopus. Other studies could consider other databases to obtain wider coverage. Moreover, it was downloaded only documents written in English, excluding studies published in other languages.

Some next steps in Quality 4.0 research should include conducting systematic literature reviews with a general and specific focus, according to research interests. Furthermore, it is important to perform a detailed searching for research gaps related with the two previously mentioned keywords set.

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REFERENCES

Albers, A., Gladysz, B., Pinner, T., Butenko, V. and Stürmlinger, T. (2016), “Procedure for defining the system of objectives in the initial phase of an industry 4.0 project focusing on intelligent quality control systems”, Procedia Cirp, Vol. 52, pp. 262-267.

Alzahrani, B., Bahaitham, H., Andejany, M. and Elshennawy, A. (2021), “How ready is higher education for quality 4.0 transformation according to the LNS research framework?”, Sustainability, Vol. 13 No. 9, pp. 5169.

Arcidiacono, G. and Pieroni, A. (2018), “The revolution lean six sigma 4.0. International Journal on Advanced Science, Engineering and Information Technology”, Vol. 8 No. 1), pp. 141-149.

Beard-Gunter, A., Ellis, D. G. and Found, P. A. (2019), “TQM, games design and the implications of integration in Industry 4.0 systems”, International journal of quality and service sciences.

Callon, M., Courtial, J. P. and Laville, F. (1991), “Co-word analysis as a tool for describing the network of interactions between basic and technological research: The case of polymer chemistry”, Scientometrics, Vol. 22 No. 1, pp. 155-205.

Carvalho, A. V., Enrique, D. V., Chouchene, A. and Charrua-Santos, F. (2021), “Quality 4.0: an overview”, Procedia Computer Science, Vol. 181, pp. 341-346.

Carvalho, A., Sampaio, P., Rebentisch, E. and Oehmen, J. (2020), "Technology and quality management: a review of concepts and opportunities in the digital transformation", International Conference on Quality Engineering and Management (ICQEM).

Chiarini, A. (2020), "Industry 4.0, quality management and TQM world. A systematic literature review and a proposed agenda for further research", The TQM Journal.

Clarivate Analytics. (2018), Web of Science Database.

Emblemsvåg, J. (2020), "On Quality 4.0 in project-based industries", The TQM Journal.

Erevelles, S., Fukawa, N., and Swayne, L. (2016), "Big Data consumer analytics and the transformation of marketing", Journal of business research, Vol. 69 No. 2, pp. 897-904.

Escobar, C. A., McGovern, M. E. and Morales-Menendez, R. (2021), "Quality 4.0: a review of big data challenges in manufacturing", Journal of Intelligent Manufacturing, Vol. 32 No. 8, pp. 2319-2334.

Flynn, B. B., Schroeder, R. G., and Sakakibara, S. (1995), "The impact of quality management practices on performance and competitive advantage", Decision sciences, Vol. 26 No. 5, pp. 659-691.

Fonseca, L., Amaral, A. and Oliveira, J. (2021), "Quality 4.0: the EFQM 2020 model and industry 4.0 relationships and implications", Sustainability, Vol. 13 No. 6, pp. 3107.

Frank, A. G., Dalenogare, L. S. and Ayala, N. F. (2019), "Industry 4.0 technologies: Implementation patterns in manufacturing companies", International Journal of Production Economics, Vol. 210, pp. 15-26.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", Journal of Manufacturing Technology Management.

Glogovac, M., Ruso, J., and Maricic, M. (2020), "ISO 9004 maturity model for quality in industry 4.0", Total Quality Management & Business Excellence, pp. 1-19.

Gimenez-Espin, J. A., Jiménez-Jiménez, D. and Martínez-Costa, M. (2013), "Organizational culture for total quality management", Total Quality Management & Business Excellence, Vol. 24 No. 5-6, pp. 678-692.

Gonzalez Aleu, F. G., and Van Aken, E. M. (2017), "Continuous improvement projects: an authorship bibliometric analysis", International Journal of Health Care Quality Assurance.

Gunasekaran, A., Subramanian, N. and Ngai, W. T. E. (2019), "Quality management in the 21st century enterprises: Research pathway towards Industry 4.0", International journal of production economics, Vol. 207, pp. 125-129.

Hyun Park, S., Seon Shin, W., Hyun Park, Y. and Lee, Y. (2017), “Building a new culture for quality management in the era of the Fourth Industrial Revolution”, Total Quality Management & Business Excellence, Vol. 28, No. 9-10, pp. 934-945.

Illés, B., Tamás, P., Dobos, P.and Skapinyecz, R. (2017), “New challenges for quality assurance of manufacturing processes in industry 4.0”, In Solid State Phenomena (Vol. 261, pp. 481-486). Trans Tech Publications Ltd.

Jacob, D. (2017), “Quality 4.0 impact and strategy handbook: getting digitally connected to transform quality management”, LNS research.

Javaid, M., Haleem, A., Singh, R. P. and Suman, R. (2021), “Significance of Quality 4.0 towards comprehensive enhancement in manufacuring sector”, Sensors International, Vol 2, pp. 100-109.

Johnson, S. (2019). “Quality 4.0: A trend within a trend”, Quality, Vol. 58, No. 2, pp. 21-23.

Kamble, S. S., Gunasekaran, A. and Gawankar, S. A. (2018), “Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives”, Process safety and environmental protection, Vol. 117, pp. 408-425.

Kannan, K. S. P. and Garad, A. (2020), “Competencies of quality professionals in the era of industry 4.0: a case study of electronics manufacturer from Malaysia”, International Journal of Quality & Reliability Management.

Kumar, R. R., Ganesh, L. S. and Rajendran, C. (2021), “Quality 4.0–a review of and framework for quality management in the digital era”, International Journal of Quality & Reliability Management.

Küpper, D., Knizek, C., Ryeson, D. and Noecker, J. (2019), “Quality 4.0 takes more than technology”, Boston Consulting Group (BCG), PP. 1-14.

Lasi, H., Fettke, P., Kemper, H. G., Feld, T. and Hoffmann, M. (2014), “Industry 4.0. Business & information systems engineering”, Vol. 6 No. 4, pp. 239-242.

Lim, J. S. (2019), Quality management in engineering: A scientific and systematic approach,. CRC Press. Boca Raton, Florida.

Lu, Y. (2017), “Industry 4.0: A survey on technologies, applications and open research issues”, Journal of industrial information integration, Vol. 6, pp. 1-10.

Mohelska, H. and Sokolova, M. (2018), “Management approaches for Industry 4.0–the organizational culture perspective”, Technological and Economic Development of Economy, Vol. 24 No. 6, pp. 2225-2240.

Nenadál, J. (2020), “The new EFQM model: What is really new and could be considered as a suitable tool with respect to quality 4.0 concept?”, Quality Innovation Prosperity, Vol. 24 No. 1, pp. 17-28.

Nerur, S. P., Rasheed, A. A. and Natarajan, V. (2008), “The intellectual structure of the strategic management field: An author co-citation analysis”, Strategic Management Journal, Vol. 29 No. 3, pp. 319-336.

Newman, M. E. (2001), “The structure of scientific collaboration networks”, Proceedings of the national academy of sciences, Vol. 98 No. 2, pp. 404-409.

Ngo, Q. H. and Schmitt, R. H. (2016), “A data-based approach for quality regulation”, Procedia CIRP, Vol. 57, pp. 498-503.

Niñerola, A., Sánchez-Rebull, M. V. and Hernández-Lara, A. B. (2021), “Mapping the field: relational study on Six Sigma”, Total Quality Management & Business Excellence, Vol. 32 No 11-12, pp. 1182-1200.

Pereira, A. C. and Romero, F. (2017), “A review of the meanings and the implications of the Industry 4.0 concept”, Procedia Manufacturing, Vol. 13, pp. 1206-1214.

Porter, M. E. and Heppelmann, J. E. (2015), “How smart, connected products are transforming companies”, Harvard business review, Vol. 93 No. 10, pp. 96-114.

Qin, J., Liu, Y. and Grosvenor, R. (2016), “A categorical framework of manufacturing for industry 4.0 and beyond”, Procedia cirp, Vol. 52, pp. 173-178.

Radziwill, N. M. (2018), “Quality 4.0: Let's Get Digital-The many ways the fourth industrial revolution is reshaping the way we think about quality”, arXiv preprint arXiv:1810.07829.

Ramezani, J. and Jassbi, J. (2020), “Quality 4.0 in action: smart hybrid fault diagnosis system in plaster production”, Processes, Vol. 8 No. 6, pp. 634.

Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P. and Harnisch, M. (2015), “Industry 4.0: The future of productivity and growth in manufacturing industries”, Boston consulting group, Vol. 9 No. 1, pp. 54-89.

Sader, S., Husti, I. and Daróczi, M. (2019), “Industry 4.0 as a key enabler toward successful implementation of total quality management practices”, Periodica Polytechnica Social and Management Sciences, Vol. 27 No. 2, pp. 131-140.

Santos, G., Sá, J. C., Félix, M. J., Barreto, L., Carvalho, F., Doiro, M., Zgodavová, K. and Stefanović, M. (2021), “New needed quality management skills for quality managers 4.0”, Sustainability, Vol. 13, No. 11, pp. 6149.

Schwartz, M. L., Kosar, C. M., Mroz, T. M., Kumar, A. and Rahman, M. (2019), "Quality of home health agencies serving traditional Medicare vs Medicare Advantage beneficiaries" JAMA Network Open, Vol. 2 No. 9, e1910622-e1910622.

Schönreiter, I. (2016, November). "Significance of quality 4.0 in post merger process harmonization", In International Conference on Enterprise Resource Planning Systems (pp. 123-134). Springer, Cham.

Sony, M. (2018), "Industry 4.0 and lean management: a proposed integration model and research propositions", Production & Manufacturing Research, Vol. 6 No. 1, pp. 416-432.

Sony, M., Antony, J. and Douglas, J. A. (2020), "Essential ingredients for the implementation of Quality 4.0: a narrative review of literature and future directions for research", The TQM Journal.

Sony, M., Antony, J., Douglas, J. A., and McDermott, O. (2021), "Motivations, barriers and readiness factors for Quality 4.0 implementation: an exploratory study", The TQM Journal.

Sony, M., and Naik, S. (2019), "Key ingredients for evaluating Industry 4.0 readiness for organizations: a literature review", Benchmarking: An International Journal.

Stock, T., and Seliger, G. (2016), "Opportunities of sustainable manufacturing in industry 4.0", Procedia CIRP, Vol. 40, pp. 536-541.

Sütőová, A., Šooš, Ľ. and Kóča, F. (2020), "Learning needs determination for industry 4.0 maturity development in automotive organisations in Slovakia", Quality Innovation Prosperity, Vol. 24, No. 3, pp. 122-139.

van Eck, N. and Waltman, L. (2010), "Software survey: VOSviewer, a computer program for bibliometric mapping", Scientometrics, Vol. 84 No. 2, pp. 523-538.

van Eck, N. J. and Waltman, L. (2017), "VOSviewer Manual. Retrieved from http://www.VOSviewer. com/download/f-y2z2.pd

Wang, S., Wan, J., Li, D. and Zhang, C. (2016), "Implementing smart factory of industrie 4.0: an outlook", International journal of distributed sensor networks, Vol. 12 No. 1, 3159805.

Xu, L. D., Xu, E. L. and Li, L. (2018), "Industry 4.0: state of the art and future trends", International journal of production research, Vol. 56, No. 8, pp. 2941-2962.

Yadav, N., Shankar, R. and Singh, S. P. (2021), "Critical success factors for lean six sigma in quality 4.0", International Journal of Quality and Service Sciences.

Závadská, Z. and Závadský, J. (2020), “Quality managers and their future technological expectations related to Industry 4.0”, Total Quality Management & Business Excellence, Vol. 31, No. 7-8, pp. 717-741.

Zonnenshain, A. and Kenett, R. S. (2020), “Quality 4.0—the challenging future of quality engineering. Quality Engineering”, Vol. 32 No. 4, pp. 614-626.

Zupic, I. and Čater, T. (2015), “Bibliometric methods in management and organization”, Organizational research methods, Vol. 18 No. 3, pp. 429-472.

Implementing sustainability as a quality factor in higher education institutions.

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STRUCTURED ABSTRACT

Purpose – This paper aims to study (identify and critically reflect on) the factors that prevent and/or allow us to implement sustainability as a quality factor in higher education institutions (HEIs).

Design/methodology/approach - The research carried out is based on qualitative analysis carried out manually (without using any computer analysis software) of the information and data collected in the literature review on the implementation of sustainability in HEIs.

Findings - It was found that in the vast majority of situations obstacles/barriers and challenges were identified rather than Critical Success Factors (CSF) and after analysis all of them will allow these organisations to be successful in their purposes.

Research limitations/implications- The limitation of this study is the fact that it is only a theoretical contribution, which needs to be validated.

Originality/value- We believe that the identification of these potential CSF associated with the implementation of sustainability in HEIs will enable them to be aware of its existence, and to foresee the need to anticipate actions, implement practices and prevent obstacles that limit it. Thus, associated to other management aspects and approaches such as Total Quality Management and continuous improvement, HEIs will be able to expect better academic results and to compete for the best students, researchers and better conditions contributing for all stakeholders.

Keywords: Sustainability, Higher Education Institutions, Critical Success Factors, Quality Factor.

Paper type: Literature review

INTRODUTION

In recent decades, a wide range of decision-makers have been interested in sustainable development. People and society can only flourish if all countries and regions experience continuous, inclusive, and sustainable economic progress (Fleacă *et al.*, 2018).

The Sustainable Development Goals (SDG) are part of the UN's "2030 Agenda for Sustainable Development" which was agreed by all UN Member States unanimously in 2015 as a "plan of action for people, planet, and prosperity" (Boeren, 2019). SDGs define and embody the global priorities for the 2030 Agenda, which has been signed by over 190 nations, and aim to bring global efforts around common goals and targets. Therefore, the United Nations' 2030 Agenda for Sustainable Development detailed the commitment of high-level stakeholders to sustainable development (United Nations, 2016). The fundamental shifts were identified and expressed in 17 universal Sustainable Development Goals (SDGs) and related targets that balanced all aspects of sustainable development, including economic, environmental, and social concerns (United Nations, 2016).

The Sustainable Development Goals create global goals and aspirations for 2030 within the boundaries of the planet, requiring worldwide action by governments, organizations, and civil society to eradicate poverty and provide a life of dignity and opportunity for everyone (Chaleta *et al.*, 2021) and serve as a rallying point for all countries — rich, poor, and middle-income – to collaborate in order to promote prosperity while protecting the environment. They recognize that reducing poverty requires approaches that encourage economic growth while also meeting a variety of social demands, such as education, health, social protection, and job opportunities, all while combatting climate change and safeguarding the environment (17 Goals to Transform Our World, 2021).

Poor alignment of aims and Goals with existing international accords and political processes; lack of efficient execution; conflicts between Goals (SDGs) and targets, non-quantified targets, and absence of and/or low-quality data for indicators were among the major flaws identified by Janouková et al. (2018).

“Higher Education Institutions (HEI) play a fundamental role in the formation of thoughts and opinions, being one of the main organs that can enhance the development of sustainable thinking (Gazzoni *et al.*, 2018, p. 48). Within this framework “universities are challenged to include the 17 Sustainable Development Goals (SDG) in the wide range of their training offers and that higher education is expected to contribute knowledge and innovation to meet societal, economic and environmental challenges through the training of both academic staff and students” (Chaleta *et al.*, 2018, p. 2).

Higher Education Institutions (HEI) are critical to the growth of society since they are one of the key agents in the transformation of professionals who will shape the labour market and societal directions. HEIs, like any other organization, require a huge number of available resources because of the large flow of people, information, and activities created and released. As a result, many businesses face major environmental risks, demanding the adoption of sustainable development strategies into their operations (Gazzoni *et al.*, 2018).

Those involved in the development of university activities must serve as a foundation for knowledge diffusion and the reinforcement of sustainable practices. Although there have been some advancements in higher education in terms of sustainability, there are still numerous obstacles to overcome (Leal Filho *et al.*, 2015).

The research and teaching objectives of HEI are all constructed to be met, and these goals are reinforced by the operational staff of the institutions (Davim & Filho, 2016; Galdeano *et al.*, 2019). Teaching and research, among other activities, can help institutions of higher education to promote sustainability (Evangelinos *et al.*, 2009; Gazzoni *et al.*, 2018).

Because of a lack of sustainability awareness, institutions and their employees are uninformed of the importance of comprehending the benefits and problems of sustainability (Salleh *et al.*, 2019).

The European Union (EU) acknowledged its commitment to sustainable development with a clear focus on three priorities for higher education systems, which are seen as the foundation of fair, open, and democratic societies, as well as sustained growth and employment, according to Fleacă *et al.* (2018): (i) quality and relevance of skill formation; (ii) more visible and comparable skills and qualifications, as well as advancement of skills intelligence; and (iii) informed career choices.

The critical factors that affect the success of sustainable development begin with a specific level of understanding from each higher education institution's stakeholders (Salleh *et al.*, 2019).

The lack of knowledge, capacities, skills, time management, and authority, as well as a lack of guiding material on sustainable development, are highlighted as challenges to implementing sustainable facilities management in universities (Awuzie *et al.*, 2015).

Since education is one of the critical success factors for HEI, several experts advocate incorporating sustainability into university curricula as a solid starting point for sustainability-related approaches (Minguet, 2011; Ahmed *et al.*, 2016; Salleh *et al.*, 2019). Aside from that, a lack of training among educators results in insufficient long-term benefits that may be provided to students, and student turnover may result in a consequence (Velazquez *et al.,* 2005).

The long-term sustainability of higher education institutions is considered as being aided by their sustainability. Environmental, economic, institutional, and integrated sustainability are all provided to the institutions (Aleixo *et al.*, 2016).

The promotion of sustainable development has heightened interest in the quality and internationalization of research in order to improve education quality (Salvioni *et al.*, 2017), demonstrating that a higher education institution with appropriate sustainable development and support will benefit in terms of quality improvement (Salleh *et al.*, 2019).

The purpose of this work is to analyse the variables that prevent and/or enable us to incorporate sustainability as a quality factor in higher education institutions (HEIs).

Apart from the introduction, the article is divided into four chapters: the framework of higher education sustainable development concerning the CSF and other relevant elements, the research methodology, results, and final considerations, study limitations, and future research.

HIGHER EDUCATION SUSTAINABLE DEVELOPMENT: CRITICAL SUCCESS FACTORS AND OTHER VERY IMPORTANT ELEMENTS

There are some studies that identify the Critical Success Factors, benefits, barriers, roles, challenges and eventually other elements associated with the sustainable development of higher education institutions. Therefore, in this section we will compile some information that we consider relevant about those elements and CSF in this type of institutions.

For sustainable development in Malaysian Public Higher Institutions, Salleh *et al.* (2019) identified knowledge, education, awareness, training, and organizational structure as critical success factors in their study. Environmental sustainability, integrated sustainability, promoting sustainability, institutional sustainability, and quality enhancement are among the benefits cited. Lack of involvement, lack of money, and lack of policy were recognized in this study as obstacles in higher education for sustainable development in Malaysian Public Higher Institutions.

Disterheft *et al.* (2015) had a different approach. They identify in their study critical success factors for participatory processes in sustainability initiatives in HEI. Therefore, the preliminary CSF presented were Communication, Enough time, Identification with goals, Making sure that the right people are at the table and that they are heard, Non-judging attitude, Personal strength and persistence, Starting on time, Stimulate positive feelings, Strategy with a goal, Support of top-management, Tangible objectives, To find out what people are caring about, Outcomes/Benefits, Capacity Building, Collaboration, Confidence, Empowerment, Increase of acceptance, More dialogue, Networking, Optimism, Positive image of the university and Raising champions. After defining several criteria, the critical success factors were ranked according to four levels of importance from very important, to not very important. Communication was frequently cited as a "very significant" critical success aspect, along with strategy with a goal, although starting on time was regarded as "less" or "least vital." Overall, importance perceptions of the participating people differ greatly amongst items, resulting in a hazy picture of the CSF ranking. CSF were categorized into structure-, process-, and person-related concerns that are influenced by each other, resulting in three broad clusters. The preliminary list was expanded or amended to include more CSF. The structure allows for enough time and availability for a participatory approach, as well as eventual support from the university's senior board members (top management), which is critical if the sustainability programme is to have an institutional influence. The participatory approach should be guided by a communication strategy that aims to discover what people care about and is built on listening, providing feedback, and maintaining a non-judgmental attitude. This type of communication should allow participants to collaborate on a strategy with clear goals that they can identify with (goal identification) and that has measurable targets. Overall, the process should emphasize capacity-building, empowerment, and the ability to raise champions, stimulate positive feelings, and offer important stakeholders a voice. Without identifying the group of participants, the advantage, or even need, of having a dedicated facilitator to lead throughout the participatory process was underlined in the cluster relating to the participants. The facilitator, on the other hand, as well as the participants, should possess specific dispositions, abilities, and participatory competences. Communication abilities, as mentioned above, as well as intuition, personal strength and persistence, flexibility, and appreciation, are examples of these. Furthermore, genuine involvement and credibility from all parties engaged, including the university's senior management, should be demonstrated in order to avoid frustration and encourage further participation.

According to Aleixo *et al.* (2016), the findings reveal that, while all stakeholders are aware of the notion of sustainability, they are unfamiliar with the concept of sustainable higher education institutions. The greatest hurdle to sustained progress in higher education is seen to be a shortage of financial resources as a result of lower financing for higher education and a decrease in the number of Portuguese university students. Actions promoting sustainability in HEIs are hampered by obstacles and this also applies to Portuguese HEI. First, there's the ambiguity and complexity of the real idea of sustainability. The absence of financial means and funding is the second issue. Third, change resistance linked to behaviours, practices, or efforts. Fourth, organizational rigidity (conservative, traditional, and conventional) can result in (a) "inefficient communication and shared information both top-down and bottom-up", "barely open to new paradigms," and (c) focus on short-term profit as a result of managerial thinking and policy making in HE.

Fifth, professors, students, staff, management, and policymakers lack dedication, engagement, awareness, interest, and involvement. The achievement of sustainability in HEIs is dependent on senior management's support. Sixth, there is a dearth of sustainability training and expertise. To these authors the barriers are inextricably linked to the challenges and drivers. In summary, they identified the following barriers to sustainability to HEIs: financial factors, difficulty in attracting students, Competitiveness, mismatch between the needs of enterprises and labour market and the training offer of HEIs, difficulty of retaining talent, demographic factors of human resources, absence of autonomy, lack of integrated strategic planning lack of autonomy that characterizes public administration, unequal opportunities between institutions, difficulty of monitoring the innovation of enterprises and socio-economic factors. Results of the interviews on relevant issues for future of HEIs are fund-raising and financing, attracting students and foreigners, transfer of knowledge, excellence and quality, internationalization, autonomy, investment in R&D, response to market needs, development of networks and partnerships, development of interdisciplinarity, motivation of human resources, long term strategic planning, qualification of faculty members, and reorganization of the business structure of institutions.

Velazquez *et al.* (2005) on their study concerning the factors which influence sustainability in higher education institutions find out that there are insufficient circumstances for successful implementation of sustainability programmes. Many barriers stand in the way of sustainability efforts succeeding on campuses around the world. Despite these challenges, though, campus sustainability efforts are thriving. According to the authors, predicting the impact of a single or a mix of barriers to a sustainability initiative is difficult. Barriers were provided in this study from the highest to the lowest degree of incidence in the information sources used. The identified barriers are as follows lack of awareness, interest, and involvement, organizational structure, lack of funding, lack of support from university administrators, lack of time, lack of data access, lack of training, lack of opportune communication and information, resistance to change, profits mentality, lack of more rigorous regulation, lack of interdisciplinary research, lack of performance indicators, lack of policies to promote sustainability on campus, lack of standard definitions of concepts, technical problems, lack of designated workplace and the “Machismo”. One of the most effective ways for adopting sustainability measures appears to be cultural awareness. The most difficult challenges for those in charge of sustainability initiative appear to be a university's conservative organizational structure and a lack of knowledge among the academic community.

In Aleixo’s *et al* (2020) study the authors collected some important information concerning sustainable development and more precisely about SDGs with possible alignment with higher education sustainable development. To achieve these goals, sufficient resources must be made accessible. These goals can only be achieved if all parties are involved and committed to taking responsibility for their actions. HEIs must recognize that by incorporating sustainability into all of their activities, particularly in education, they can provide students with the skills they need to address society's problems for future well-being. It is critical that Education Sustainable Development in higher education teaches graduates to make responsible decisions and improves employability skills.

Larrán Jorge *et al.* (2015) pointed out from other authors that a lack of support from university administrators, a lack of timely sustainability information and communication, a generalised lack of performance indicators, a lack of interest, awareness, and involvement, a lack of sustainability training, a lack of incentives, a lack of time, a lack of financial resources, and resistance to implementing sustainability initiatives in higher education institutions are all obstacles to success. They have determined on their study the factors that influence the implementation of sustainability practices in Spanish universities. They are students, society, staff, corporate governance, continuous improvement, environment and companies. These findings imply that the leadership role played by some universities may be one of the key elements in the implementation of sustainability policies by HEI.

Verhulst and Lambrechts (2015) state, based on studies, especially from the perspective of the university system, focus on and identify barriers to change and critical success factors. Based on multiple other authors and publications, the barriers to change in higher education are described as follows: lack of Sustainable Development (SD) awareness, insecurity and threat to academic credibility from teachers, over-crowded curricula, lack of support, SD considered to have little or no relevance to the course or discipline, uncertainty of the efforts required to engage with and incorporate SD, discipline restricted organisational structures; academic conservationism/traditions that tie universities to old mechanistic mental models. In their research the authors identify in literature several barriers and present them in three clusters: barriers related to the lack of awareness, to the structure of higher education, and to the lack of resources.

The barriers for the integration of SD in HE related to the lack of awareness are:

1. Lack of interest and involvement of the majority of the students and staff members
2. Lack of support by management and policy makers
3. Lack of professionalisation and training of teachers
4. Lack of policy making in order to promote sustainability
5. Lack of standard definitions and concepts of SD in HE
6. Lack of recognition, change agents for SD are often not taken seriously
7. SD seen as a threat to academic freedom and credibility
8. SD is not seen as relevant to a certain course or discipline.

The ones related to the structure of higher education are:

1. Conservative disciplinary structure of HEI, barely open to new paradigms
2. Inefficient communication and shared information both top-down and bottom-up
3. Resistance to change by education and research
4. Focus on short-term profit as a result of managerial thinking and policy making in, HE
5. Lack of interdisciplinary research as a result of insufficient coordination and cooperation
6. Overcrowded curriculum
7. Focus on content-based learning.

Those related to the lack of resources are:

1. Lack of money, SD is not seen as a priority for funding
2. High work pressure and lack of time, the responsible for SD combines this task often with other tasks
3. Lack of access to information, due to absence of measuring instruments or by unwillingness of staff
4. Lack of consistent legislation
5. Lack of qualitative and quantitative performance indicators
6. Technical problems
7. Lack of physical place.

The studies of the authors listed above and now analysed, allowed the identification of important elements for the implementation of sustainability in HEIs. Although each one reported these elements in different contexts and realities, namely the countries in which these studies were conducted, it is possible to verify the existence of common and also divergent obstacles/barriers and challenges. Considering the current importance that sustainability represents for HEIs, this constitutes as a quality factor, to be observed by them and to which they should pay the greatest attention in the context of compliance with the 2030 Agenda.

The added value of this information lies in the fact that it is possible to assess the possibility of obstacles/barriers and challenges being seen from the perspective of critical success factors and thus, HEIs are able to outline strategies, action plans and activities that enable them to achieve the sustainability for which they desire.

RESEARCH METODOLOGHY

The findings of this study are based on a qualitative examination of the subjects. A literature review was conducted in order to determine the Critical Success Factors related with the implementation of sustainability in higher education institutions.

The following were the steps performed to process the data:

- First step: Literature review
- Second step: Identifying the Keywords or Key-expressions
- Third step: Collecting systematized information on CSF, the barriers/obstacles, and problems/challenges associated to Sustainability
- Fourth step: Analysis of data from the identification of those factors in the implementation of sustainability for a better understanding of the Critical Success Factors in HEIs.

The data is examined qualitatively without the use of any other analysis software, and the results are organized in tables for easier understanding.

RESULTS

We shall proceed to the analysis of the results after studying the literature on the issues and gathering other information about higher education institutions.

Considering the information obtained in the various studies carried out by several authors, namely, Salleh *et al.* (2019), Disterheft *et al.* (2015), Aleixo *et al.* (2016), Velazquez *et al.* (2005), Aleixo's *et al* (2020), Larrán Jorge *et al.* (2015) and Verhulst and Lambrechts (2015) and described in the previous chapter, it was found that in the vast majority of situations obstacles/barriers and challenges were identified rather than critical success factors. Many of the identified elements are repeated, so it was necessary to make a first screening to eliminate the repetitions.

The barriers/obstacles and challenges listed by the various authors and identified in table 1 end up defining or establishing the critical success factors, which are nothing more than the elements or conditions that enable the success of something, and also the opportunities for improvement.

Table 1 – Obstacles/barriers and challenges in the implementation of Sustainability in HEIs.

OBSTACLES/BARRIERS	CHALLENGES
Ambiguity and complexity of the real idea of **sustainability** Lack of **sustainability training** and expertise lack of **policies** to promote **sustainability** on campus lack of **timely sustainability** information and **communication** **SD** seen as a threat to academic freedom and credibility **SD** is not seen as relevant to a certain course or discipline Lack of standard definitions and concepts of **SD** in HE lack of standard definitions of concepts	High work pressure and lack of **time**, the responsible for SD combines this task often with other tasks
Lack of **policy** making in order to promote **sustainability** **resistance** to implementing **sustainability** initiatives	
Absence of **financial** means and **funding** **financial** factors lack of **financial** resources lack of **funding** Lack of **money**, SD is not seen as a priority for **funding** socio-economic factors	**fund-raising and financing** **investment** in R&D
Professors, students, staff, **management** Lack of support by **management** and **policy** makers	
mismatch between the needs of enterprises and labour **market** and the **training** offer of HEIs Lack of professionalisation and **training** of teachers	response to **market** needs
Change resistance linked to behaviours, practices, or efforts Lack of recognition, **change** agents for SD are often not taken seriously **Resistance** to **change** by **awareness** and research	
organizational rigidity (conservative, traditional, and conventional) Conservative disciplinary **structure** of HEI, barely open to new paradigms	**reorganization** of the business **structure** of institutions university's conservative **organizational structure**
Policymakers lack dedication, engagement, **awareness**, interest, and **involvement** Focus on short-term **profit** as a result of managerial thinking and **policy** making in HE **profits** mentality lack of support from university administrators	cultural **awareness**
difficulty in **attracting** students	**attracting** students and foreigners
absence of **autonomy**	internationalization, **autonomy**
lack of integrated **strategic** planning	long term **strategic** planning
lack of opportune **communication** and information Inefficient **communication** and shared information both top-down and bottom-up	
Lack of interest and **involvement** of the majority of the students and staff members	
Lack of **interdisciplinary** research as a result of insufficient coordination and cooperation	development of **interdisciplinarity**
lack of designated **workplace**	
Lack of **physical place**	
lack of **knowledge** among the academic community	transfer of **knowledge**

Competitiveness unequal opportunities between institutions difficulty of retaining talent difficulty of monitoring the innovation of enterprises Lack of qualitative and quantitative performance indicators	development of networks and partnerships
Lack of access to information, due to absence of measuring instruments or by unwillingness of staff Overcrowded curriculum Focus on content-based learning	excellence and quality
lack of incentives	qualification of faculty members
demographic factors of human resources	motivation of human resources
lack of more rigorous regulation Lack of consistent legislation	
lack of data access	
technical problems "Machismo"	

Source: Adapted from Salleh *et al.* (2019); Disterheft *et al.* (2015); Aleixo *et al.* (2016); Velazquez *et al.* (2005); Larrán Jorge *et al.* (2015); Verhulst and Lambrechts (2015)

The table compiles a list of obstacles/barriers and challenges that HEIs may face when implementing the sustainability dimension as a quality factor. Although these elements are not identified or attributed any order of importance or relevance, we believe that institutions, in possession of this information, will be able to verify their importance and, furthermore, will be able to anticipate, in some way, any problem and avoid or eliminate the obstacles/barriers and overcome the challenges, successfully concluding the implementation of sustainability within their institution.

FINAL CONSIDERATIONS

According to Aleixo *et al.* (2020), sustainability is still a new political goal, but it is necessary for all institutions to perform their responsibilities to generate proactive interactions among institutions, agents, and people. According to Leal Filho *et al.* (2015), the Sustainable Development Goals may provide a chance to overcome problems in HEIs in order to achieve sustainability. Universities can now make a big contribution to the sustainability challenge because of their role as centers of learning, innovation, and research. Universities, on the other hand, can also take a range of approaches to sustainability challenges, all of which should be explicitly stated in their strategic plans (Sisto, 2020).

We believe that the strong alignment that exists between Critical Success Factors for implementing sustainability and HEIs' strong desire to be more sustainable would enable them to more readily contribute to the SDGs that they consider strategic and to achieve excellence in these dimensions. With this paper, we hope to contribute to the debate that has raged for at least two decades on sustainability literature and, more recently, the SDGs and their alignment with other themes like Total Quality Management. We also believe that, in addition to their own aspirations and strategies in terms of quality and sustainability, HEIs should assess their alignment with the European Commission's published European university policy and the national strategy for higher education specified by each country.

The limitation of this research is the fact that it is only a theoretical contribution, which needs to be validated.

We propose that future studies examine the sustainability Critical Success Factors and compare them to the Critical Success Factors of Total Quality Management (TQM) implementation, which might have yet to be identified in this new context of the 2030 Agenda, in order to determine whether they should be considered as CSFs in TQM implementation as well.

A future study might focus on understanding how TQM and Sustainability CSFs relate to the SDGs and how HEIs can contribute to them in order to promote sustainability as a quality factor throughout time.

REFERENCES

- 7 Goals to Transform Our World (2021). Available online: https://www.un.org/sustainabledevelopment/ (accessed on 26 December 2021).
- Ahmed, U., Majid, A. H., Zin, M. L., Phulpoto, W., & Umrani, W. A. (2016), Role and impact of reward and accountability on training transfer. Business and Economics Journal, 7(1). http://dx.doi.org/10.4172/2151-6219.1000195.
- Aleixo, A. M., Leal, S., & Azeiteiro, U. M. (2016), Conceptualization of sustainable higher education institutions, roles, barriers, and challenges for sustainability: An exploratory study in Portugal. Journal of Cleaner Production, 1–10. https://doi.org/10.1016/j.jclepro.2016.11.010.
- Aleixo, A., Azeiteiro, U., Leal, S. (2020), Are the Sustainable Development Goals being implemented in the Portuguese Higher Education Formative Offer?, International Journal of Sustainability in Higher Education, 21(2), https://doi.org/10.1108/IJSHE-04-2019-0150.
- Awuzie, B., Emuze, F., Ngowi, A. (2015), Critical success factors for smart and sustainable facilities management in a South African University of Technology. In: Smart and Sustainable Built Environment (SASBE) Conference 2015. p. 377.
- Boeren, E. (2019), Understanding Sustainable Development Goal (SDG) 4 on “quality education” from micro, meso and macro perspectives. International Review of Education, 65(2), 277-294. https://doi.org/10.1007/s11159-019-09772-7.

- Chaleta, E., Saraiva, M., Leal, F., Fialho, I., & Borralho, A. (2021), Higher Education and Sustainable Development Goals (SDG) - Potential Contribution of the Undergraduate Courses of the School of Social Sciences of the University of Évora. Sustainability, 13(4), 1828. https://doi.org/10.3390/su13041828.
- Davim, J. P., & Filho, W. L. (2016), Challenges in Higher Education for Sustainability. London: Springer International Publishing Switzerland. https://doi.org/10.1007/978-3-319-23705-3.
- Disterheft, A., Caeiro, S., Azeiteiro, U. M., & Leal Filho, W. (2015), Sustainable universities–a study of critical success factors for participatory approaches. Journal of Cleaner Production, 106, 11-21. https://doi.org/10.1016/j.jclepro.2014.01.030.
- Evangelinos, K. I., Jones, N., & Panoriou, E. M. (2009), Challenges and opportunities for sustainability in regional universities: a case study in Mytilene, Greece. Journal of Cleaner Production, 17(12), 1154-1161. https://doi.org/10.1016/j.jclepro.2009.02.020.
- Fleacă, E., Fleacă, B., & Maiduc, S. (2018), Aligning strategy with sustainable development goals (SDGs): Process scoping diagram for entrepreneurial higher education institutions (HEIs). Sustainability, 10(4), 1032. https://doi.org/10.3390/su10041032.
- Galdeano, D., Ahmed, U., Fati, M., Rehan, R., & Ahmed, A. (2019), Financial performance and corporate social responsibility in the banking sector of Bahrain: Can engagement moderate? Management Science Letters, 9(10), 1529-1542.
- Gazzoni, F., Scherer, F. L., Hahn, I. S., de Moura Carpes, A., & dos Santos, M. B. (2018), O papel das IES no desenvolvimento sustentável: estudo de caso da Universidade Federal de Santa Maria. Revista Gestão Universitária na América Latina-GUAL, Florianópolis, v. 11, n. 1, 48-70. https://doi.org/10.5007/1983-4535.2018v11n1p48.
- Janoušková, S., Hák, T., & Moldan, B. (2018), Global SDGs assessments: Helping or confusing indicators?. Sustainability, 10(5), 1540. https://doi.org/10.3390/su10051540.
- Larrán Jorge, M., Herrera Madueño, J., Calzado Cejas, M. Y., & Andrades Peña, F. J. (2015), An approach to the implementation of sustainability practices in Spanish universities. Journal of Cleaner Production, 106, 34–44. doi:10.1016/j.jclepro.2014.07.035.
- Leal Filho, W., Manolas, E. & Pace, P. (2015), The future we want: key issues on sustainable development in higher education after Rio and the UN decade of education for sustainable development, International Journal of Sustanability in Higher Education, v. 16, n. 1, p. 112-129. https://doi.org/10.1108/IJSHE-03-2014-0036.

- Minguet, P. A., Martinez-Agut, M. P., Palacios, B., Piñero, A., & Ull, M. A. (2011), Introducing sustainability into university curricula: An indicator and baseline survey of the views of university teachers at the University of Valencia. Environmental Education Research, 17(2), 145–166. https://doi.org/10.1080/13504622.2010.502590.
- Salleh, M. I., Habidin, N. F., Noor, K. M., & Zakaria, S. Z. S. (2019), The development of higher education for sustainable development model (HESD): Critical success factors, benefits, and challenges. International Journal of Academic Research in Progressive Education and Development, 8(4), 47-54.
- Salvioni, D. M., Franzoni, S., & Cassano, R. (2017), Sustainability in the higher education system: An opportunity to improve quality and image. Sustainability (Switzerland), 9(6), 1–27. https://doi.org/10.3390/su9060914.
- Sisto, R., Sica, E., Cappelletti, G. M. (2020), Drafting the strategy for sustainability in universities: a backcasting approach. Sustainability, 12(10), 4288.
- United Nations (2016), Transforming Our World: The 2030 Agenda for Sustainable Development; United Nations: New York, NY, USA, available at: https://sdgs.un.org/2030agenda (accessed 20 March 2022).
- Velazquez, L., Munguia, N., & Sanchez, M. (2005), Deterring sustainability in higher education institutions: An appraisal of the factors which influence sustainability in higher education institutions. International Journal of Sustainability in Higher Education, 6(4), 383–391. https://doi.org/10.1108/14676370510623865.
- Verhulst, E., & Lambrechts, W. (2015), Fostering the incorporation of sustainable development in higher education. Lessons learned from a change management perspective. Journal of Cleaner Production, 106, 189–204. doi:10.1016/j.jclepro.2014.09.049.

Service Quality Evaluation of Saudi Arabia Flowers Market

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STRUCTURED ABSTRACT

Purpose (Mandatory) - The paper's main purpose is to investigate, analyze and reflect upon the Service Quality of the Flower Market in Saudi Arabia.

Design/methodology/approach (Mandatory) - This study applied the SERVQUAL model to evaluate the florist shops in Saudi Arabia within the major cities Riyadh, Jeddah and Dammam/Khobar. The model of SERVQUAL will offer the evaluation of service quality of the market of flowers in Saudi Arabia. The idea of this study is to see the market of flowers in the perception of the owners and managers of the florist shops in order to find an evaluation of their services.

Findings (Mandatory) - The overall mean of the whole market including all dimensions is 4.14 out of 5. The scores in general looks good and tends to be in the high side. However, there is still some gaps and areas of improvements especially when zooming into the groupings, which was one of the fantastic tools for feather investigations.

Research limitations/implications- This is the first stage of the research project as further research should be done next to find more about the flowers market of Saudi Arabia. The point of view of the customers is important in order to explore more into this market in the kingdom.

Originality/value (Mandatory) - Flowers are number one gifts in most events globally. In Saudi Arabia, flowers used in all big and small personal events such as newborn baby and graduations as well as the Eids and valentine's day.

Keywords: SERVQUAL, Flower Market, Saudi Arabia, Survey

Paper type: Research paper

INTRODUCTION

Internationally, Saudi Arabia is known for the oil industry as the biggest producer in the world. What many people do not know however, that the Kingdom has many developed non-Oil industries. Manufacturing, constructions, electricity, water distribution and agriculture are examples of the many non-Oil industries that the Saudi Arabia has already and can improve more to cope with the vision of 2030. NEOM is also a non-Oil project that will capture many non-Oil industries and write a new story of the new Saudi.

With the huge expansion of flowers market nowadays in Saudi Arabia, it is important to evaluate the service quality that the existing shops are providing for the customers. The demand and supply are very high in such market and the verity of services is high too. It is an old market but many changes were done especially in marketing the business. These changes made it easier for customers and harder for new small investors to compete with the huge companies. However, the service quality will make a room for new comers in this market with their new innovations and creativity.

The flowers market in Saudi Arabia consists of three main pillars, the supplier who imports the flowers and provide them to the Saudi market. The second pillar is the florist's shops that gets the flowers from the suppliers and provide many services with the cut flowers. Last and more important is the customers that gets the products and services from the florists. The florist's shops provides many services to the customer apart from making the many types flowers available in the shop. Arranging the flowers for the customers with ready designs or customized is one of the most important service in such market. Selling flowers accessories like vases and boxes and gift-wrapping papers. Delivering the orders can be a service that the shop for flowers provides in Saudi.

This study will give an overview of the flowers market in Saudi Arabia and focus more in the second pillar (florist shops). Using a few independent variables, the study will test service quality of the examined shops to answers the two key research questions. First question is What is the general perception of service quality among flowers shops in Saudi Arabia?. Then the study would focus more to answer the second question, what are the main areas of improvement needed to boost the quality of services?

There will be an adaptation of the SERVQUAL to develop a flowers market service model, which will include the SERVQUAL dimensions and customizes them to suit the flowers market. The data that was used in this study included surveying the owners and managers of the florist shops in the market of Saudi. The examination was done in the main cities of Saudi Arabia, Riyadh the capital city of the kingdom, Jeddah from the West and Dammam/Khobar from the East. The florists' shops were chosen carefully to have the top shops of these cities base on google rating and reviews.

LITERATURE REVIEW

Flowers market globally

Caring about flowers and growing them is a universal practice and they have been used in many ways under many cultures, which they were drawn 120,000 years ago in ancient Egyptian graves (Huss et al., 2017). Huss et al. (2017) found that silk flowers were existed in China 2000 year ago. Flowers played a great role in the 19th century socially where they were used much in a romance perspective and other occasions such as weddings and illness like our recent time (Seaton, 2012). The demand of cut flowers increased nowadays all around the world with the help of new shipping systems that allowed the flowers to move from east to west vice versa (Steen, 2010).

Flowers usage can be categorized into three categories according to Hunt (1972), first are the gifts driven by the verity of traditions then comes the social and religious events like weddings and Eid and last is the home decorations. There are many flowers types that consumers choose depends on the events itself as typically, the purchasing of flowers is attached to an occasion (Yue & Hall, 2010). The consumption of flowers internationally is around $25 billion per year (de Boon, 1990). There are more than 90 countries that are actively practicing in the industry of flowers (Xia et al., 2006).

Florist is “a retailer of flowers and ornamental plants” (Florist Definition & Meaning (Dictionary.com). The industry of florist is relatively small industry comparing with other retail industries and most of the florist shops includes a full-time manager (Havas, 1965). The floriculture industry places the retail florist in a strategic position to represent them in front of the public (DeWERTH et al., 1960). According to (MissouriFFA.org), a retail flower shop normally includes a manager to supervise the floral designer and other employees which they sell and arrange flowers to the customers.

Smith (1982) mentioned that the biggest producer of flowers in the worlds is Europe as well as the biggest consumer including Netherlands and Germany. According to Pedroza (2008), most flowers in the French market comes through the Dutch auction system, which provides the flowers from most continents. This auction sells more than 50% that European exported which make the Netherlands the European flowers center and the world’s most flowers trade market (Petrovska, 2013). Netherlands is the highest of exporting the cut flowers to Europe with 60% then 9% from Kenya and 4-3% each from Ecuador, Ethiopia and Belgium (CBI, 2017). BBC (2022) reported that $1.7 billion was the UK market of cut flowers worth in 2018 and 90% of these flowers were imported from the Netherlands. Petrovska (2013) described the flower market in most countries in Europe where the highest share of cut flowers are distributed to the florists then supermarkets and others like small markets and street sales have a very smaller share.

The florist industry in the US has started with small greenhouses then developed into a more focused and specialized industry and expanded in 1950 (Sorensen et al., 1958). According to AIPH (2022), the USA is number one in importing the flowers in the last 10 years and is not in top 10 of exporting flowers. However, United States is number three in the worlds on producing cut flowers but that’s serves only the US market domestically (Bonarriva et al., 2003) In south America, Colombia has the flowers market as one of the main sources of income for the country with receiving billion dollars from exporting flowers every year (Fernandez, 2015). Africa have a big share in exporting cut flowers to Europe leading with Kenya then Ethiopia, South Africa and Zimbabwe (Ara & Hosen, 2017).

Apart from Europe and America, Japan and Hong Kong flower markets have the capability to supply cut flowers to Asia region (Gunnerod, 1991). Other countries in Asia including Middle East was able to export special types of flowers with total Asia exporting of almost $1.1 billion (Steen, 2010). Pun et al (2019) describes the florist market in Nepal that it was a growing market as its value was $ 147,000 in 1994 and increased up to 16 million dollars. In Bangladesh started the fresh cut flowers recently as only a few flower shops were there in the 80’s, and nowadays, 24% of Bangladesh exports are agriculture including flowers with demand from middle eastern countries, USA, Europe and Japan (Mony, 2018).

Egypt was an old exporter of cut of flowers to the market of Saudi Arabia since the 70’s (Garoyan & Palmer, 1982). Since the 90s Netherlands, Kenya, Malaysia, Jordan and India were the biggest suppliers of cut flowers to the market of Saudi Arabia (Amer et al., 1996). Almost 1% of Kenya’s cut flowers was exported to the Saudi Market in 1999 (Dolan et al.,2012). According to Sutton (2002), Saudi Arabia imported around 14 tons of dry and fresh flowers from Australia in 2001. India was a great and steady exporter of flowers to Saudi Arabia (Balamurugan, 2020). The importing from India was increasing year after year as in 2016 Saudi imported 413 tons of cut flowers then around 500 tons in 2017 (Bhagat et al., 2019). Bangladesh also played a role in exporting flowers to the Middle East including Saudi Arabia and other countries in the world (Islam& Rahman, 2013).

Florists shops services

The customers expect the tangible products from the florist industry such as the flowers and its related materials but these products to be sold are attached with very high services that are performed by the florist shops (Becker, 1993). Berry (1986) described the services of the florist shops with many forms, starting with making the cut flowers available to customers in the market. Another service of florist shop he mentioned is providing the verity of flowers with different styles in great quantity. Also considering selling the products in an attractive shop with its good location and great organizing of the needed products as a service of this industry. There are more services of the florist industry that can be included such as personal assistance from salesperson, customizing the arraigning the flowers, special orders, telephone sales and delivery. All the above services are normally available in a typical florist shop.

The florist shops in Bangladesh according to Mony (2018) usually have set of designs of flowers arraignments for the customers to choose from then they can also customize it for the customer if needed. Base on Corda (2019) study, what differentiate flower shop from another is the supplementary services rather that the core services such as the consultation giving to the customer along with the great hospitality, order tracking and making information about the products, location of shop, prices etc. available. On the other hand, he commented on the core services of the florist industry and described it as the benefits that the customer expects from the shop where without this high quality service, the customer would not come to the shop.

Service quality

Alex & Thomas (2011) describe the service quality as the area between the customers desire and what they actually get. Service quality is the point where the service meets the customers' expectations (Lewis & Mitchell, 1990). It is the feeling that customers have when the service was provided or received a product (Karim, 2020). Quality can be also descried as the customer's whole experience when receiving a product or service (Onyeaghala, 2016). Service quality is related with the customer loyalty for this business and more importantly the customer satisfaction along with financial and marketing strategies (Cronin et al., 2000). The higher the quality service is performed, the more customer's satisfaction it is (Guo et al., 2008).

Satisfaction for a customer comes when the demand of that customer reached to that expectation and fulfilled their need (Karim, 2020). Cengiz (2010) mentioned that the experience of customer satisfaction can be in different situations when associated with goods and services. In addition, the greater customer satisfaction rating, the more it indicates of the success of the business which show that customer satisfaction can be a good tool to evaluate the quality of the service. Customer satisfaction can increase any business sales and profits (Onyeaghala, 2016).

SERVQUAL model

In 1985, the concept of Service quality (SERVQAUAL) was publish by A. Parasuraman, Leonard Berry and Valarie Zeithaml (Grapentine, 1998). The original study by Parasuraman et al. came up with 10 dimensions of the model SERCQUAL then later, some dimensions were neglected by further studies and ended up with the common 5 dimensions; Tangibility, Reliability, Responsiveness, Assurance and Empathy (Vencataya et al., 2019). The model was descried by Karim (2020) to be one of the best tools to measure the customer satisfaction for the service provider as it shows the pros and cons in the service analytically to find the gaps to be able to fix later on.

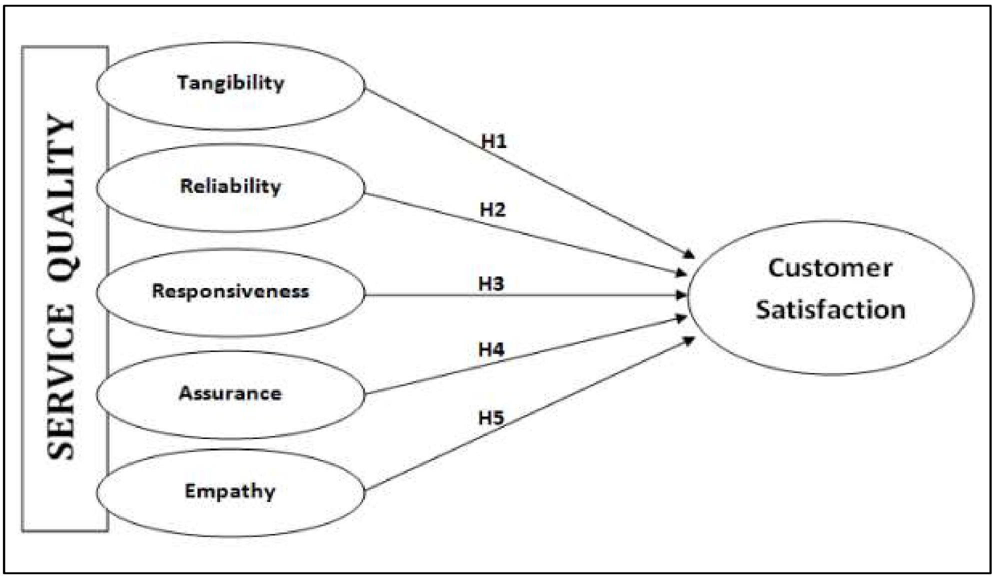

Figure 1 – SERVQUAL model, source: (Vencataya et al., 2019)

Lim et al. (1999) and Abukhalifeh & Som (2015) defined the five dimensions as follows:

- Tangible: any tangible aspects that is related to the provided product or services such as tools and equipment are used to provide them, the shop and building and its design and furniture, the look of the employees.
- Reliability: The ability of the company or shop to perform the promised services dependably and accurately.
- Responsiveness: willingness to help customers and provide prompt service.
- Assurances: the employees' knowledge and courtesy levels and their ability to convey and confidence. This dimension includes competency, credibility and security.
- Empathy: Caring and personalized attention that the firm provides to its customers. This dimension also includes access, communication and understanding the customer.

METHODOLOGY

This study applied the SERVQUAL model to evaluate the florist shops in Saudi Arabia within the major cities Riyadh, Jeddah and Dammam/Khobar. The model of SERVQUAL will offer the evaluation of service quality of the market of flowers in Saudi Arabia. The idea of this study is to see the market of flowers in the perception of the owners and managers of the florist shops in order to find an evaluation of their services to the public that they know better than anyone in the market.

SERVQUAL model:

This study used the five dimensions of the SERVQUAL model stating with Reliability, Responsiveness, Assurance, Empathy and lastly Tangibles. All main 16 questions in the questionnaire including all five dimensions had a rating from 1 to 5 for the owner and mangers of the flowers shop to choose from. The rating starts with strongly disagree then disagree, neutral, agree and lastly strongly agree. Each of these ratings has a weight where strongly disagree represent the weight of 1 and so on. These weights after collecting the surveys, would get the mean of each point asked and will show the gap of this point at this market of flowers in the Kingdom of Saudi Arabia. The rate and its weights presented as follows:

Table 1 – Rating and weight of the used questionnaire

Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
1	2	3	4	5

Sampling

The market of flowers in Saudi Arabia is mainly consist of suppliers, florists and customers. In this study, the examination was on the services that the florists perform and to find the best outcome, it was chosen to survey the service provider and to see the gaps through surveying the top shops. The survey was done through the owners of the top florist shops, according to google rating, in the Saudi market in the motioned cities. This study was done through the owners' shops point of view of the flowers market and their services to the customer in order to find the quality obtained of such services in the flowers market of Saudi.

According the ministry of commerce website, there are over 8000 registered licenses of selling flowers in the Kingdom including the expired licenses (https://mc.gov.sa/ar/eservices/Pages/Commercial-data.aspx). Riyadh is the highest with 1660 registered licenses and Jeddah and Dammam/Khobar with 1005 and 453 respectively. However, according to Google Map, around 180 flowers shops are there in Riyadh, 196 shops in Jeddah and 200 florists in Dammam/Khobar. The flowers shops chosen were in three areas as mentioned, Riyadh, Jeddah and Dammam/Khobar, which they are considered to be in the top cities in Saudi Arabia in terms of supply and demand especially in the flowers market. Also, according to Google Trend (محل ورد قريب مني, florist, بوكيه ورد ,توصيل ورد, floral - Explore - Google Trends), they are the top 3 cities in Saudi based on the search terms. The chosen flowers shops were 79 shops in which 30 shops are located in Riyadh, 25 in Jeddah and 24 shops are between Dammam and Khobar. These chosen shops are the top in their location according to google rating and reviews. Almost all of these shops have rating above 4 out of 5 and more than 30 reviews.

Table 2 – List of tested cities and no. of shops

Geographic area	No. of shops
Riyadh	30
Jeddah	25
Dammam/Khobar	24

Questionnaire

To use the model of SERVQUAL, there should be a surveying via questionnaire sent to the examined candidates. In this study, the survey monkey tool was used to perform the surveying by making the questionnaire in the platform. The questionnaire started with six demographic questions:

- Years in the flower market
- Number of average orders per day
- Number of employees
- Online shopping availability
- No. of branches
- Location of shops

The rest of the questionnaire included the five dimensions of SERVQUAL model with the chosen 16 points explained above.

Data collection

The questionnaire was sent to the 79 chosen flowers shops' owners and managers via phone call and emails. The respondents were 34 and only 30 were correctly answered as the 4 neglected surveys had missing information. The 30 questionnaires were gathered and exported into SPSS software to calculate the weights got from all points asked. The means of the points were found individually then for each dimension and last for the overall market. Some grouping was done for more investigation and better results for such massive market and many factors that changes the results from group of shops to another.

RESULTS

Demographics

The research grouped the florist shops into 6 different grouping questions. The first question was asking about the years that the flower shops practiced this business in the flower market of Saudi Arabia. From the 30 responses received, there are 6 flowers shops that were in the business of flowers for 1-2 years only which represent 20% of the examined shops. Almost another 20% (5 shops) have 3-5 years in the market of flowers. The rest of the shops are 6 year or more in the business which they are 19 flowers shops (80%).

Table 3 – Results of first grouping question

	Years	No. Shops
Years in The Flower Market	1-2	6
	3-5	5
	6+	19

The second demographics question was about the number of average orders per day that each shop gets. This question shows the more busier shop and the more profitable too. For this question, there were four ranges for the owners and managers of the flowers shops to choose from. 9 shops out of the 30 shops gets 1-10 orders per day which are 30% of evaluated shops. Another 30% of the shops have 26-40 orders per day which is the highest orders range. The majority with 40% of the flowers shops have 11-25 orders per day. Last grouping range was 41 and more orders per day but none of the shops reached this numbers of orders according to the received questionnaires.

Table 4 – Results of second grouping question

	Orders	No. Shops
Number of average orders per day	1-10	9
	11-25	12
	26-40	9

The numbers of employees were important to know as the study also assigned to be the third grouping question. Almost 47% of the flower's shops have 3-5 employees with according to the 14 shops that chose this range. 6 shops however have 1-2 employees only which are 20% of the shops whereas another 6 shops have 6-10 employees. Only 4 shops have 11 and more employees as their staff in the shops which was the least chosen range which represent only 13% of the shops.

Table 5 – Results of third grouping question

	Employees	No. Shops
Number of employees	1-2	6
	3-5	14
	6-10	6
	11+	4

It was also important for the study to see if the flowers market has turned into e-shopping like the other markets. The next grouping question was to find out whether they have any online platform that they sell and present their products on or not. More than two third of the tested flowers shops answered with Yes that they have online shopping available for the customers. However, 9 shops do not have the service of online shopping available for the customers which is not a small number.

Table 6 – Results of fourth grouping question

	Answer	No. Shops
Online Shopping Availability	Yes	21

	No	9

Number of branches of the same brand of the flowers shops was another grouping question to how big the brand is and if this is a reason of performing better service with more quality or less. More than half of the 30 shops have only one branch (17 shops). 37% of the shops that the study examined have 2-4 branches. Only two flowers shops have 5-10 branches of the same brand and none have 11 or more branches.

Table 7 – Results of fifth grouping question

	Branches	No. Shops
No. of Branches	1	17
	2-4	11
	5-10	2
	11+	0

The last grouping question was geographic as the shops were asked about the location of their shops or branches out of the three examined cities Riyadh, Jeddah and Dammam/Khobar. The total number in this question was more than 30 and the reason is that some of the brands have branches in more than one city. In Khobar/Dammam, the examined shops were 13 shops. 12 shops were from Riyadh and 10 shops are located in Jeddah.

Table 8 – Results of sixth grouping question

	City	No. Shops
Location of Shops	Khobar/Dammam	13
	Riyadh	12
	Jeddah	10

SERVQUAL dimensions:

All five dimensions examined had rating of 1-5 in each item for the owners and managers of the shops to choose from as 1 is strongly disagree and 5 is strongly agree. The first dimension examined was Reliability. Starting with performing the orders on promised time and more than half of the shops (16) evaluated with Agree with the weight 4. 11 shops evaluated their shops with full mark of 5 and only 3 shops rated their service with neutral. The mean for this item is 4.27 out of 5 but when focusing on the shops that have high number of orders per day (26-40) with 5 employees or less, the means dropped to 3.75.

Performing the right services at the first time, is the next item examined under reliability. The mean for this item is 4.24 out of 5 for all the 30 shops examined. The majority of shops rated their shops with agree (4) and 11 shops highly rated this item with 5 but only 4 had neutral as their rate. The mean again drops to 3.75 with the same group that have high orders per day and 5 employees or less.

The third Reliability question was about the inventory and availability of products and services. 15 shops scored 4 (Agree) which represent 50% of the tested shops and only 4 shops scored with Strongly Agree (5). However, in this item, many shops (8) scored with 3 and some even evaluated their store with 2 which shows the issues in the inventory. For that, the mean this time score was lower with 3.67 out of 5 across all 30 flowers shops. The last point is the rate of error-free transactions that the stores have. Overall, the score of the shops is 4.1 but with the high orders per day, the scored decreased to 3.78 especially those shops that have the online shopping as the score decreased even more to 3.57.

Table 9 – Results of Reliability dimension items

Reliability						
Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean
	(1)	(2)	(3)	(4)	(5)	
The orders always finish on promised time	0	0	3	16	11	4.27
The services always be performed right at the first time	0	0	4	14	11	4.24
The services and products are always available for customers	0	3	8	15	4	3.67
The store has error-free transactions	0	1	4	16	9	4.1

The second tested dimension in this study was Responsiveness, which included four main points that evaluated the shops with. Regarding the first subject of the pace of the staff service, most of the shops owners and managers evaluated with Agree and strongly Agree with only 1 Disagree and the rest of 6 shops were Neutral. The Mean overall was fairly high with a score of 4.1 out 5. However, in regard of the ability of staff to handle customer’s complaint directly and immediately, the score overall was low with only 3.3 out of 5 where almost half of these shops were Neutral, Disagree and Strongly Disagree. Another low score was in willingness of the store to handle returns and exchange as overall, the average score was only 3 out of 5. This low score comes from the 11 shops that Disagree and Strongly Disagree with 7 shops' owners that had the score of 3 (Neutral). On the other hand, a good average rate of 4.5 for all the shops was the evaluation of willingness of the staff to help the customer.

Table 10 – Results of Responsiveness dimension items

Responsiveness						
Items	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean
Staff give prompt service	0	1	6	12	11	4.1
Staff can handle customers complaint directly and immediately	2	4	8	15	1	3.3
This store willingly handles returns and exchange	5	6	7	8	4	3
Staff are always willing to help customers	0	0	1	13	16	4.5

Assurance was the third tested dimension in this study, which mainly focused on the staff of the shops with three main points. All of these three points scored with high average that is above 4.5 out of 5 overalls as all shops were evaluated with Agree (4) and Strongly Agree (5). First point was to test how trained the staff are to give the best quality service and the mean was 4.53. Just about the same score, the staff friendliness was evaluated with 4.55 as well as the efficiency of the staff with 4.5.

Table 11 – Results of Assurance dimension items

Assurance						
Items	Strongly Disagree (1)	Disagree (2)	Neutral (3)	Agree (4)	Strongly Agree (5)	Mean
Staff are trained well	0	0	0	14	16	4.53
Staff are friendly	0	0	0	13	16	4.55
Staff are efficient	0	0	0	15	15	4.5

Only two main evaluating points for the Empathy dimension that were suitable for the flowers market and they are almost attached to each other. The individual attention that the store gives for customer as well as the personal attention that the staff gives to customers. The average score for all shops was fairly high with 4.47 and 4.27 respectively. However, there is a relation between the number of employees and the score of these two points where the higher number of employees in a store, the higher the score it in most cases.

Table 12 – Results of Empathy dimension items

Empathy						
Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean
	(1)	(2)	(3)	(4)	(5)	
The store gives individual attention	0	0	1	14	15	4.47
Staff give personal attention	0	0	2	18	10	4.27

The last dimension of the model of SERVQUAL that the study tested was Tangible. With three points, two of them focused on the store of flowers itself. First one was about how modern the equipment and fixtures of the stores look. Overall, the stores scored an average of 4.37 out of 5. With the same score, the average of all shops was evaluated on the attraction of the store and its facilities. The third and last point was about the availability of delivering the orders to customers and the score overall seems good or even high. However, when zooming in into the market, it is clearly showing that the delivery of orders is more attached with the online shopping as the average score dropped for the non-online shops to 3.67 out of 5.

Table 13 – Results of Tangibles dimension items

Tangibles						
Items	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Mean
	(1)	(2)	(3)	(4)	(5)	
The Store has modern-looking equipment and fixtures	0	0	2	15	13	4.37
The Store and its facilities are visually attractive	0	0	1	17	12	4.37

The Store can Deliver the orders to the customers	2	1	2	6	19	4.3

CONCLUSIONS, & RECOMMENDATIONS AND FURTHER RESEARCH

The study examined service quality of the flowers market of Saudi through the florist shops in the main cities of the Kingdom, Riyadh, Jeddah and Dammam/Khobar. The chosen florists' shops were 79 shops but the examination was performed on 30 shops across these three locations. The overall mean of the whole market including all dimensions is 4.14 out of 5. The scores in general looks good and tends to be in the high side. However, there is still some gaps and areas of improvements especially when zooming into the groupings, which was one of the fantastic tools for feather investigations.

In regard of Reliability, there are a few gaps that clearly attached to the group of shops that had many orders per day (26-40) but they have a few number of employees (5 or less). For the items, finishing the order on time and performing the service right on the first time, the means included all shops were 4.27 and 4.24 respectively. However, in the mentioned group, both rates dropped to 3.75 which shows the clear gap that was created by accepting more orders than the capacity of the shop. In this case, the shops should either hire more employees to fulfil the need and the high demand or refuse the orders until increase the capacity of the shop rather than making delays and wrong orders.

Another gap was found on Reliability, which is the transaction errors in which the mean overall was 4.1, the errors in transactions increases and the factor is the high orders again (26-40) as the rate dropped to 3.78. Another factor also made it even worse with rate of 3.57 when the high demanded shops are selling online. This issue will make an impact on the trust and loyalty between the shop and the customers. For the online shopping, there should be a good support team to try to ease the situation and fix the transactions as soon as possible.

The inventory is another issue of this flowers industry especially for the natural cut flowers. The score also shows the difficulty of keeping all products and services available at all time as the average rating across all 30 shops is 3.67. Forecasting and inventory are hard to handle but with the chemistry and trust between the shop and supplier, the inventory can be managed better even with the natural cut flowers.

There are two low means in the dimension of Responsiveness, which shows the area of improvements that can be implemented. The first is 3.3 out of 5 for the employees that can handle the complaint of customers directly and immediately. This shows a lack of empowerment that the managers and owners did not give the authority of the employees to deal with customers issues. For this to be improved training should be given for employees to deal with the different situations and some more authority should be given to them.

The other gap in Responsiveness was in the return policy that the flowers shops have. The evaluation of such point was 3 only out of 5 averagely. It is difficult to return cut flowers once they are used into a design. However, it is also difficult to tell the customers that the shop does not have return policy. There should be policy of return for non-flowers products, which some shops do. In addition, there should be a system of returning the cut flowers, even if the customers can be given a 10% penalty of returning the flowers and give them the rest of the money.

This is the first stage of the research project, as further research should be done next to find more about the flowers market of Saudi Arabia. The point of view of the customers is important in order to explore more into this market in the kingdom. This next research will open even more room of improvement of the service quality as the customers shall expand some existing gap or even discover new once that the owners and managers did not see in this study.

REFERENCES:

- Abukhalifeh, A. N., & Som, A. P. M. (2015). "Servqual: A Multiple–Item Scale for Measuring Customer Perceptions of Restaurants' Service Quality". Advances in Environmental Biology, 9(3), 160-162.
- Alex, D & Thomas, S. (2011), "Impact of Product Quality, Service Quality and Contextual Experience on Customer Perceived Value and Future Buying Intentions", India. European Journal of Business and Management.
- Amer S., Jabarin, R.F., Hattar, M. & Khatab J. (1996), "A business plan for export of cut flowers from Jordan". Prepared for The Agricultural Marketing Development Project Amman.
- Ara, H., & Hosen, M. M. (2017), "Exploring the floral marketing practices: an investigation of the retail floral traders of Bangladesh", European Journal of Business and Management, 9(8), 28-38.
- Balamurugan, l. (2020), "Export potentiality of cut flower industry: a case study on Hindustani flower industry with special reference to Tamil Nadu", Dogo Rangsang Research Journal.
- Becker, W. A. (1993), "Products, services, and consumer perceptions of service quality in the retail floral industry of Texas", Doctoral dissertation, Texas A&M University.
- Berry, L. L. (1986). "Retail businesses are services businesses". Journal of Retailing, 62(1), 3-6.
- Bhagat, A. A., Badgujar, C. D., Bhosale, S. S., & Supe, V. S. (2019), "An economics analysis for export of fresh cut rose flowers from India", Journal of Pharmacognosy and Phytochemistry, 60, 100-00.
- Bonarriva, J., Jabara, C., & Burket, S. (2003), "Industry and Trade summary cut flowers". US Intl. Trade Commission Publ, 3580.
- CBI (2017), "What competition do you face on the European cut flowers and foliage market?", available at: https://www.cbi.eu/market-information/cut-flowers-foliage/competition (accessed 5 May 2022).
- Cengiz, E. (2010), "Measuring customer satisfaction: must or not", Journal of naval science and engineering, 6(2), 76-88.
- Corda, C. O. (2019), "The Flower Service Concept Applicable in Public Service National Land Agency of Demak Regency", Doctoral dissertation, Universitas Muhammadiyah Surakarta.
- Cronin, J., Brady, M. K. and Hult, G. M. (2000), "Assessing the effects of quality, value, and customer satisfaction on consumer behavioral intentions in service environments", Journal of Retailing, 76(2): 193-218.

- de Boon, I.H. (1990), "A world perspective on more flowers for more people", Professional Plant Growers Assn, News 21:7, 10-11.
- DeWERTH, A. F., Sorensen, H. B., & Odom, R. E. (1960), "Marketing and Business Management Practices of Texas Retail Florists", Miscellaneous Publication/Texas Agricultural Experiment Station; No. 407.
- Dolan, C., Opondo, M., & Sally Smith, S. (2012). "Gender, rights & participation in the Kenya cut flower industry", Natural resources institute.
- Fernandez, J. (2015), "An optimization model to agroindustrial sector in Antioquia (Colombia, South America)", In Journal of Physics: Conference Series (Vol. 622, No. 1, p. 012002), IOP Publishing.
- Garoyan, L., Foytik, J., & Palmer, S. C. (1982), "Potentials for Exporting Cut Flowers from Egypt", Economics Working Paper Series No. 69.
- Grapentine, T. (1998), "The history and future of service quality assessment", Marketing Research, 10(4), 4-21.
- Guo, X., Duff, A. and Hair, M. (2008), "Service quality measurement in the Chinese corporate banking market", International Journal of Bank Marketing, 26(5): 305-27.
- Gunnerod, P. K. (1991), "Marketing cut flowers in Japan and Hong Kong", In International Trade Forum (No. 3, p. 28). International Trade Centre.
- Havas, N. (1965), "Profile of the Retail Florist Industry", US Department of Agriculture, Economic Research Service, No. 741.
- Hunt, A. (1972), "The marketing of flowers in the United Kingdom", European Journal of Marketing.
- Huss, Efrat & Yosef, Kfir & Zaccai, Michele. (2017). The Meaning of Flowers: A Cultural and Perceptual Exploration of Ornamental Flowers. The Open Psychology Journal. 10. 140-153.
- Islam, S. S., & Rahman, R. (2013), "Flower cultivation in Jessore-a prospective field of economic boom", International Journal of Innovative Research and Development (ISSN 2278–0211), 2(7).
- Karim, M. M. (2020), "Servqual Model for Measuring Customer Satisfaction: An Analysis of Quantitative Data", Noble International Journal of Business and Management Research, 4(12), 117-125.
- Lewis, B.R. and Mitchell, V.W. (1990), "Defining and measuring the quality of customer service", Marketing Intelligence & Planning, Vol. 8, No. 6, pp. 11-17
- Lim, P. C., Tang, N. K. H. and Jackson, P. M. (1999), "An innovative framework for health care performance measurement", Managing service quality. 9(6): 423-33.

- Mony, R., & Sk, R., & Jahan, M., & Islam, I., & Uddin, Dr. (2018), "Flower industry in Bangladesh: exploring floriculture potential", International journal of business, social and scientific research, 50-56.
- Onyeaghala, O. (2016), "Servqual model as performance evaluation instrument for small and medium sized enterprises (SME): Evidence from customers in Nigeria", European Scientific Journal, 12(28), 520-540.
- Pedroza Filho, M. X. (2008), "Changes in the governance structure of the French market for cut flowers: challenges and opportunities for foreign suppliers", In IAMO Forum 2008 (pp. 7-p).
- Petrovska, I. (2013), "The cut flower markets of Poland and Ukraine in the EU", Zeszyty Naukowe Szkoły Głównej Gospodarstwa Wiejskiego w Warszawie. Problemy Rolnictwa Światowego, 13(4).
- Pizano M. (2022), "Global trends in the cut flower trade" , available at: https://aiph.org/floraculture/news/global-trends-in-the-cut-flower-trade/ (accessed 1 May 2022).
- Pun, U., & Tripathi, K., & Kafle, D. (2019), "Prospects and challenges of floriculture business in federal Nepal". Nepal horticulture society.
- Sutton, S. (2002), "Export flower industry: A review of recorded statistics". RIRDC.
- Seaton, B. (2012), "The language of flowers: A history", University of Virginia Press.
- Smith, C. N. (1982), "Marketing Practices of European Flower Growers", In Proceedings of the Florida State Horticultural Society (Vol. 95, pp. 186-189).
- Sorensen, H. B., DeWerth, A. F., & Jensen, E. R. (1958), "Production Methods and New Markets for Texas Florist Crops", Texas FARMER Collection.
- Steen, M. (2010), "A world of flowers: Dutch flower auctions and the market for cut flowers", Journal of Applied Horticulture, 12(2), 113-121.
- Vencataya, L., Pudaruth, S., Juwaheer, R., Dirpal, G., & Sumodhee, N. (2019), "Assessing the impact of service quality dimensions on customer satisfaction in commercial banks of Mauritius", Studies in Business and Economics, 14(1), 259-270.
- Xia, Y., Deng, X., Zhou, P., Shima, K., & Teixeira da Silva, J. A. (2006), "The world floriculture industry: Dynamics of production and markets" Floriculture, ornamental and plant biotechnology, 4,336-347.
- Yue, C., & Hall, C. (2010), "Traditional or specialty cut flowers? Estimating US consumers' choice of cut flowers at non calendar occasions", HortScience, 45(3), 382-386.

– (2019), "Made on earth the 4,000 mile flower delivery", available at: https://www.bbc.com/future/bespoke/made-on-earth/the-new-roots-of-the-flower-trade/ (accessed 7 May 2022).

APPENDIXES 1: QUESTIONNAIRE

Table 1- Part (1) Grouping Questions

Years in The Flower Market	1-2
	3-5
	6+
Number of average orders per day	1-10
	11-25
	26-40
Number of employees	1-2
	3-5
	6-10
	11+
Online Shopping Availability	Yes
	No
No. of Branches	1
	2-4
	5-10
	11+
Location of Shops	Khobar/Dammam
	Riyadh
	Jeddah

Table 2- Part (2) SERVQUAL

Dimensions	**Items**	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
		(1)	(2)	(3)	(4)	(5)
Reliability	The orders always finish on promised time					
	The services always be performed right at the first time					
	The services and products are always available for customers					
	The store has error-free transactions					
Responsiveness	Staff give prompt service					
	Staff can handle customers complaint directly and immediately					
	This store willingly handles returns and exchange					

	Staff are always willing to help customers					
Assurance	Staff are trained well					
	Staff are friendly					
	Staff are efficient					
Empathy	The store gives individual attention					
	Staff give personal attention					
Tangibles	The Store has modern-looking equipment and fixtures					
	The Store and its facilities are visually attractive					
	The Store can Deliver the orders to the customers					

APPENDIXES 2: GOOGLE TREND

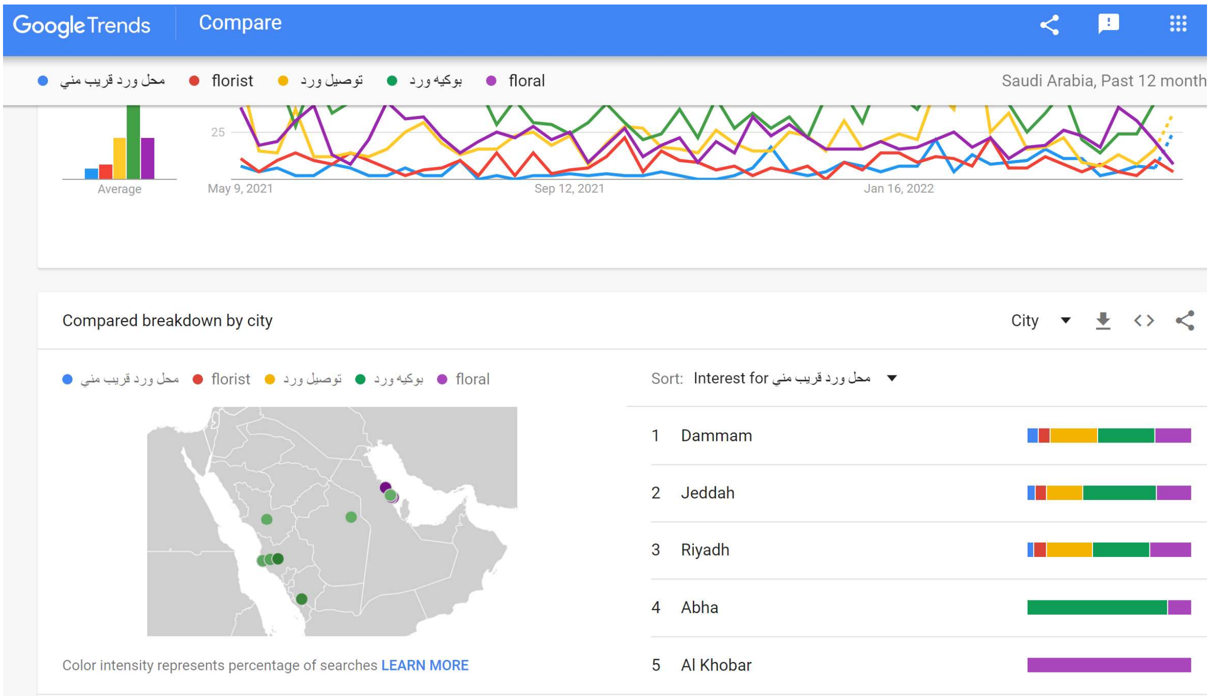

Figure 1- Google Trend indication of the top 3 cities for flowers search terms

Integration of Project Monitoring and Quality Management: A case study.

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Purpose: The transformations and challenges of higher education demand flexibleness and modernization of universities. This article presents a quality assurance approach for monitoring and controlling projects in a Chilean state-owned university. It aims to integrate project management standards to Quality Management System -QMS-.

Methodology: A questionnaire was developed and used to help identify gaps and evaluate the level of compliance with quality management requirements. To standardize processes, a documentary analysis and revision of work flows was made. Finally, the Project Management Institute standard was integrated with the QMS guidelines.

Findings: The data analysis and of semi-structured interviews showed that the teams had varying levels of knowledge regarding project management and process support provided by the unit under study. The support to internal stakeholders has focused in providing cost and procurement management, but schedule and quality management guidelines has been also provided. Other areas, such as scope, communications, risks and stakeholders have been guided by project leaders. This required, for this study, defining common processes for project monitoring and control, including standardization.

Research limitations: There exists low adherence to project management systems -PMS- in public universities, having scarce to none literature available for making comparisons.

Originality/value: This article provides guidelines to establish a PMS integrated to a QMS for a public university to promote the use of maturity models.

Keywords: Quality Management Systems – Higher Education – Project Management

Paper type: Case study

INTRODUCTION

Projects have been widely used to achieve objectives and to monitor strategic plans, being "a temporary effort carried out to create a unique product, service or result" (Project Management Institute [PMI], 2017, p. 4). Project activities create value for organizations and their stakeholders through results. Thus, project management is used by several organizations, including Higher Education Institutions –HEIs–, generating the need to develop mechanisms that ensure the alignment of their projects with their organizational strategies (Solarte and Sánchez, 2014; Villar, 2013).

An approach used by HEIs is to implement planning and quality management systems, incorporating elements of their regular operations as an effort to increase their learning capacity and organizational performance (Pérez and Shek, 2014). As a result, some institutions are using the standard ISO 21.001:2018, which includes as a requirement, "to establish, develop and maintain a strategic plan for the organization" (Instituto Nacional de Normalización [INN], 2018, p.11). The use of such a standard requires periodic updating of its plans (Summers, 2006). However, for Latin American universities, the planning process is usually participatory and voluntary, but it is also costly, lengthy, and its results are usually biased by the political power of its actors (Barreda, 2016).

In Chile, fiscal contributions for state-owned universities are made up of basal and competitive funds from the Higher Education Program of the Ministry of Education –MINEDUC–; historically, however, awarding such financial resources did not require universities to have a strategic plan in place (Reich et al., 2010). Nevertheless, strategic planning became a natural option for such institutions. Thus, over the last 30 years, Chilean universities have adjusted their internal dynamics under premises of efficacy and efficiency towards satisfying national guidelines. The results obtained and the compliance of accreditation criteria and quality indicators are their main achievements so far. Fulfilling the institutional commitments derived from either their strategic plan, improvement plan, program plans, or university projects, contribute to achieving their vision and mission. This is also supported by their actions in the short and long term (Srinivas et al., 2015) and by institutional accreditation processes. As an example, law N° 21.091 states that a university can be accredited in either three categories: excellence, advanced, and basic. The category granted relies on the evidence provided, which should prove how strategic and continuous institutional improvement objectives are achieved.

Most of the time, managing strategic and improvement plans, requires an adequate implementation of projects funded by MINEDUC.

The regulatory framework for the management of institutional programs and projects is regulated by the legal provisions of MINEDUC and the Comptroller General of the Republic, institution responsible for overseeing the compliance with legal and regulatory provisions of public resources, such as accounting and financial activities (Contraloría General de la República, 2019). Both supervising organizations require universities to have accountability processes for public resources, being a priority to document such processes to comply with regulations, usually supported by a Quality Management System –QMS– or a Project Management Systems –PMSº–. Although the identification and verification of elements of project management allows determining the level of maturity of an organization, literature is still scarce on applications and development of these models in public HEIs (Madero, 2018; Vélez et al., 2018), none of them in Chile. Also, none of the literature reviewed includes guidelines for integrating PMS with an internal QMS. This article provides a methodology for integrating PMS processes managed by the Institutional Projects Monitoring Division –known as DSPI– with the guidelines of the Integral Quality Management System of the Universidad de La Frontera –known as SGIC–. It uses the standards for project direction and management.

CASE STUDY

The challenges faced by Chilean HEIs require them to be proactive, but also flexible and forefront (García, 2013); a common strategy being the creation of project management units. This action aided by universities responding assertively to their functions and lessen, somewhat, the underlying financial responsibilities of their operations. Said institutions have made efforts to establish and demonstrate having a QMS able to evaluate performance levels in all areas of accreditation: institutional management, undergraduate and graduate programs, research, outreach and community engagement, and quality assurance, among others; the QMS aims to improve the quality of products and services (Celis et al., 2021).

Universidad de La Frontera is a state-owned, autonomous institution founded in 1981. It is driven by a systematic and effective commitment to continuous improvement, having achieved remarkable results since its creation. In the period 2000-2019, the institution was awarded 92 projects totaling 30 015 000 000 Chilean pesos (USD 36 810 154), positioning itself as the fourth university with the highest national funding in the period (MINEDUC, 2020). The administration of those projects is carried out by the DSPI, a unit that accompanies and assures the quality of the execution and closure of programs and projects; it also ensures compliance with the duties of the agreements and with legal regulations (Universidad de La Frontera, 2014).

The DSPI, prior to implementing the methodology described by this article, lacked having support processes written which could assure quality in the monitoring and control of projects. It is known that having standardized –and common– support processes for project management fosters greater effectiveness and efficiency of institutional activities and of resources utilization. Giving the nature of each product and service provided by the institution, it believed necessary to "adapt existing paradigms and to develop new ones to achieve quality assurance" (Diez et al., 2012, p.212).

Therefore, the first step was to analyze the SGIC requirements needed for developing the DSPI's QMS; so, the institutional process map provided the flow of information, the relationships, and the interactions between the university processes, which are divided into: strategic processes, which include all areas and define guidelines at the institutional level; key or operational processes, which are specific for basic needs and purposes; and support processes, that assist operational activities and process implementation (Jara, 2019, p.4).

LITERATURE REVIEW

Currently, there is no consensus regarding the concept of "quality assurance" in higher education (Lemaitre et al., 2012). Espinoza et al. (2020) defines it as "the process by which we aid and guarantee compliance with certain minimum standards in terms of achievements, operation and development" (p.40), using different and broad scopes, such as: evaluation processes, management and planning, among others. According to Cabrera (2008, in Espinoza et al., 2020, p.41), quality assurance is "the set of coordinated activities to direct and control an organization, in order to ensure and improve internal management and, consequently, the quality of its services and products".

In project management, "the quality assurance approach resides in the processes used in the project" to assure stakeholders that "the final product will meet their needs, expectations and requirements" (PMI, 2017, p.289). Therefore, defining common processes and procedures indicating *how* to proceed at the organizational level in response to internal and external factors, while ensuring quality in project management, requires special attention in certain areas. Areas such as: knowing and understanding work-flow dynamics; available tools; cultural and organizational governance framework; project governance framework; and feasible plans for design, implementation, and operation, in order to reconcile expectations among system stakeholders (INN, 2015).

The standards used for project management vary depending on geographical distribution, culture, local economy and politics, whether the project is for the public or private sector, among many other factors. Reyes et al. (2018) points out that the main and most common standards and/or methodologies for project management are: the PMBOK® guide, the PRINCE2 method, and the ISO 21500:2012 standard. There is also the ISO 10006:2017, which proposes guidelines for project quality management.

On the other hand, maturity models are strategic tools used to identify and prioritize areas and actions meant to improve an organization, focusing on the capacity of its processes and its overall performance (Madero, 2018). There are approximately 46 Organizational Maturity Models in Project Management, all of which stem from total quality management. Among the most recognized models are: Organizational Project Management Maturity Model –OPM3–; Project Management Maturity Model –KPM3–; and Project, Program and Portfolio Management Maturity Model –P3M3– (Castellanos et al., 2014). Although project management has spread to various sectors and there is a significant number of models, not all of them are part of the public domain, such as the Colombian Maturity Model CP3M © V.5.0 (Vélez et al., 2018). This article uses the KPM3 model, using 5 maturity levels in the management of organizational projects: Level 1–Common Language: we recognize the importance and necessity to understand and use project management techniques, in order to achieve a common basis for communicating how projects are being managed; Level 2 –Common Processes: we recognize the need to use similar management processes in all our projects, so successful processes can be replicated into other projects; Level 3 –Singular Methodology: we focusing on project management and recognize that we must use only one methodology to manage the processes; Level 4 –Benchmarking: we recognize the importance of improving processes to achieve competitiveness in the market, and we establish comparative criteria based on other organizations within our environment; Level 5 –Continuous Improvement: the organization has the ability to carry out an analysis of the results obtained in comparison with its environment, and to make decisions about its methodologies (Castellanos, 2014). This is of public domain.

RESEARCH METODOLOGHY

A mixed-type investigation was used (Hernández et al., 2010), supported by exploratory and descriptive methods, using qualitative and quantitative strategies (Jara, 2019). Figure 1 presents a graphic scheme of the methodology used for integrating the PMS with the internal QMS.

In order to gather qualitative and quantitative information, a convenience sampling of 19 people was used, including: Director of Analysis and Institutional Development; Chief of DSPI; administrative-financial staff of DSPI (4); Directors and/or those responsible for projects being executed and/or recently closed (13).

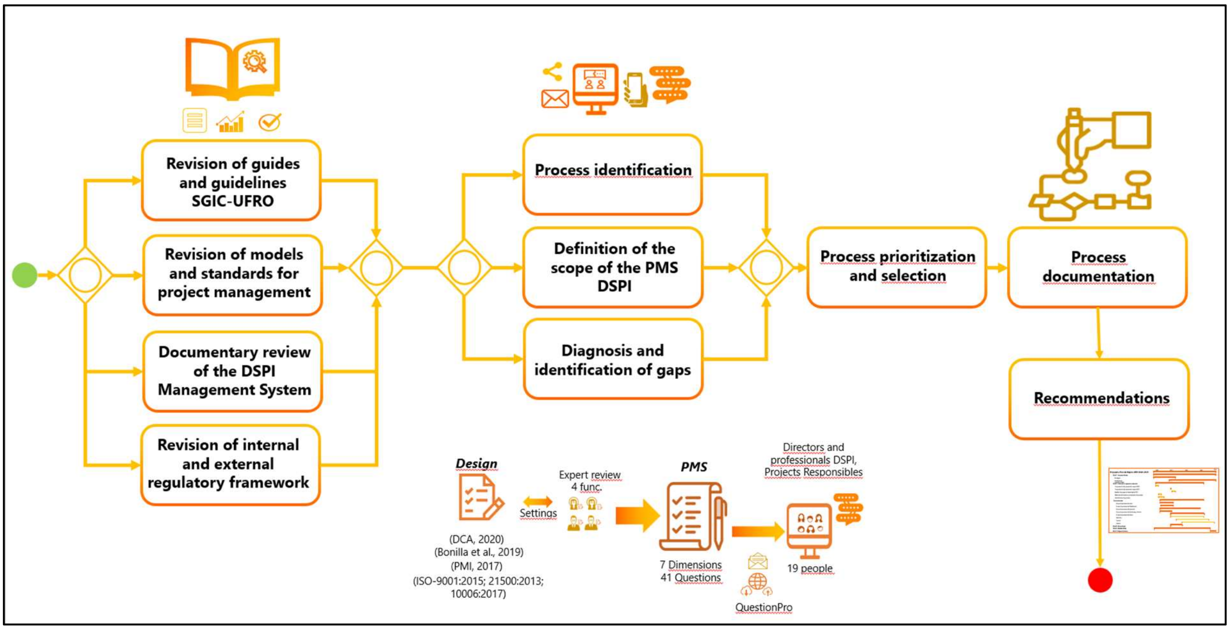

Figure 1 – Methodology

First, a documentary review was made for: guidelines and orientations of the SGIC; models and standards for project management; DSPI Management System; internal and external regulatory regulations of the operation and accountability of institutional funded projects for Chilean HEIs.

Subsequently, the management support processes linked to the regular operations of the DSPI were identified and the scope of the PMS was defined. At the same time, a questionnaire was designed to carry out a diagnosis and identification of PMS gaps, using an instrument applied by the institution to support the design of QMS for units belonging to the SGIC. This consists of a checklist based on ISO 9001:2015. The instrument was adapted to evaluate management systems involving project management, taking as reference: (i) the instruments applied by Calderón (2012), Madero (2018), and Bonilla et al. (2019) used to evaluate the level of organizational maturity in project management; (ii) the PMI:2017 project management standard; (iii) the ISO 21500:2013 on Project Management; and (iv) ISO 10006:2017 Quality Management Systems-Guidelines for project quality management. Later, the instrument was validated by an expert panel made of four people experienced in implementing institutional projects and in the design and implementation of quality management systems.

Next, the selected sample of participants was identified and invited to answer the questionnaire through the QuestionPro platform. The purpose of applying the instrument was to assess the requirements for quality management in a project-based management system, following the guidelines and orientations defined by the institution on its SGIC.

Then, the processes were sorted according to their priority and the most relevant ones were chosen to be documented and eventually standardized. To support these activities, correlation diagrams, affinity graphs, flow diagrams, and cause-effect diagrams were made; qualitative primary information was obtained through open-question and semi-structured interviews held with DSPI staff using the ZOOM platform. These helped identify events, processes, instructions, activities carried out by project teams and the used tools and techniques. It also provided information about the platforms and information technology systems being used, as well as other elements that were documented as part of the support processes for PMS. After analyzing qualitative and quantitative information, four processes were documented, following the institutional guidelines. Such processes were prioritized based on the results of the quality management tools applied and the suggestions of the DSPI's Chief.

Finally, and based on the analysis carried out from the responses to the questionnaire, the open-question and semi-structured interviews, literature review, good practices from the standards, the recommendations that emerged during the meetings and work sessions, and the study of the internal and external regulations of projects funded by MINEDUC, several recommendations were made to the DSPI´s PMS. They aimed to improve the management of DSPI's support processes, to move forward in the level of maturity regarding project management, and the integration of the internal QMS into the SGIC.

RESULTS AND DISCUSSION

According to the EIGP (2016), the UNE-ISO 21500:2013 uses a strategy established by senior management defining the project governance framework and how it is applied at the project level to achieve its objectives. Therefore, the institution is an organization that presents a hybrid strategic planning, considering its regular operations –strategic, operational or support processes– and the projects –temporary efforts–. Both contribute to a proper accomplishment of performance levels and to the execution of all processes established in the "Strategic and Resource Planning" section of the Institutional Process Map.

The organizational strategy deployment of the institution was drawn (Figure 2) to help understand the relationship between the SGIC and the strategic and resource planning macro-process, including its regular operations and the interaction with temporary activities, such as projects.

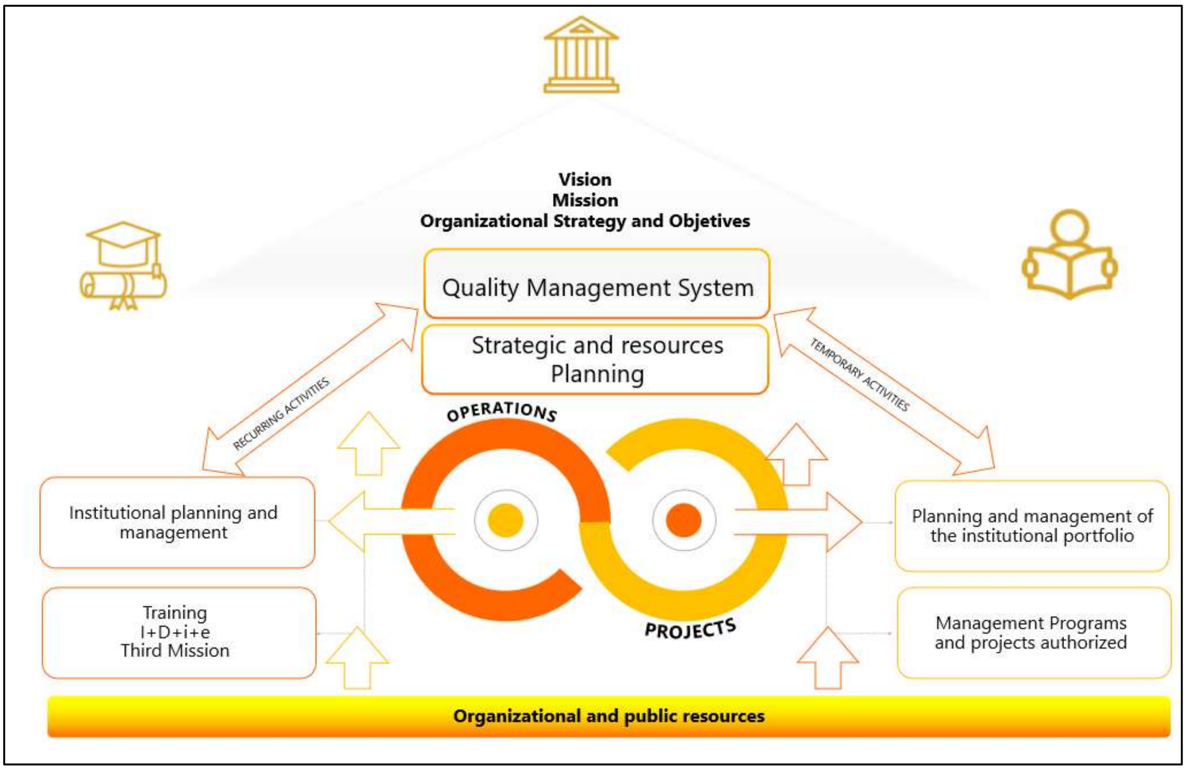

Figure 2 – Organizational Strategy Deployment

At the individual project level, each Project Manager personalized the value delivery approach to carry out its work: predictive, adaptive or hybrid. They adapted the approach to their environment. However, several administrative-financial support processes were not documented, making them non-standardized processes.

This situation had to be adjusted to accomplish the regulatory and legal framework, using a predictive approach. Although DSPI provides administrative-financial support to project directors or managers through access to information and templates, it cannot influence the results of the projects, and thus, has little control over said projects.

As an example, during the period 2000-2019 the portfolio of projects and proposals exhibited a wide and diverse complexity in terms of purpose, number of proposals, nature, funds origin, timetable, and number of units involved. Those projects were associated with 11 types of funds, generally with more than one purpose, with an average financing of 326 000 000 Chilean pesos (USD 399 803) and an average duration of 28 months; 43 units managed those projects, both jointly and decentralized from the DSPI (See Figure 3). All of them were administratively supervised by the DSPI.

The heterogeneity of the projects presented a challenge when generating an institutional PMS, which ended up being complex, yet valuable and capable of promoting good practices, knowledge development, as well as consolidating the skills and competencies of project teams. Most of the projects focused on reducing gaps, improving previous indicators and results, and prioritizing the use of resources. Such strategies ensure compliance and strategic alignment between institutional projects and organizational goals (Labrada and López, 2010).

According to the literature, the institution's DSPI must play the role of a Project Management Office –PMO– "An organizational structure that standardizes the governance processes related to the project and facilitates the exchange of resources, methodologies, tools and techniques" (PMI, 2017, p. 48). This was consistent with the roles of the DSPI. According to Bonilla et al. (2019), other roles include developing and managing: policies, procedures, project databases, reports and documentation, lessons learned, and tools. Depending on the level of control and influence PMOs have over their projects, they can be supportive, controlling or directive. They can also be classified by the type of service offered: administrative support, specialized service, consultancy and advice, governance, and control.

Therefore, including new roles for the DSPI required that the institution provided guidelines and resources to strengthen its organizational structure and improve its PMS. This would facilitate the adequate foreseeing of its processes, mechanisms and governance based on the unique characteristics of each project or proposal, ensuring quality in the execution and the results (PMI, 2017).

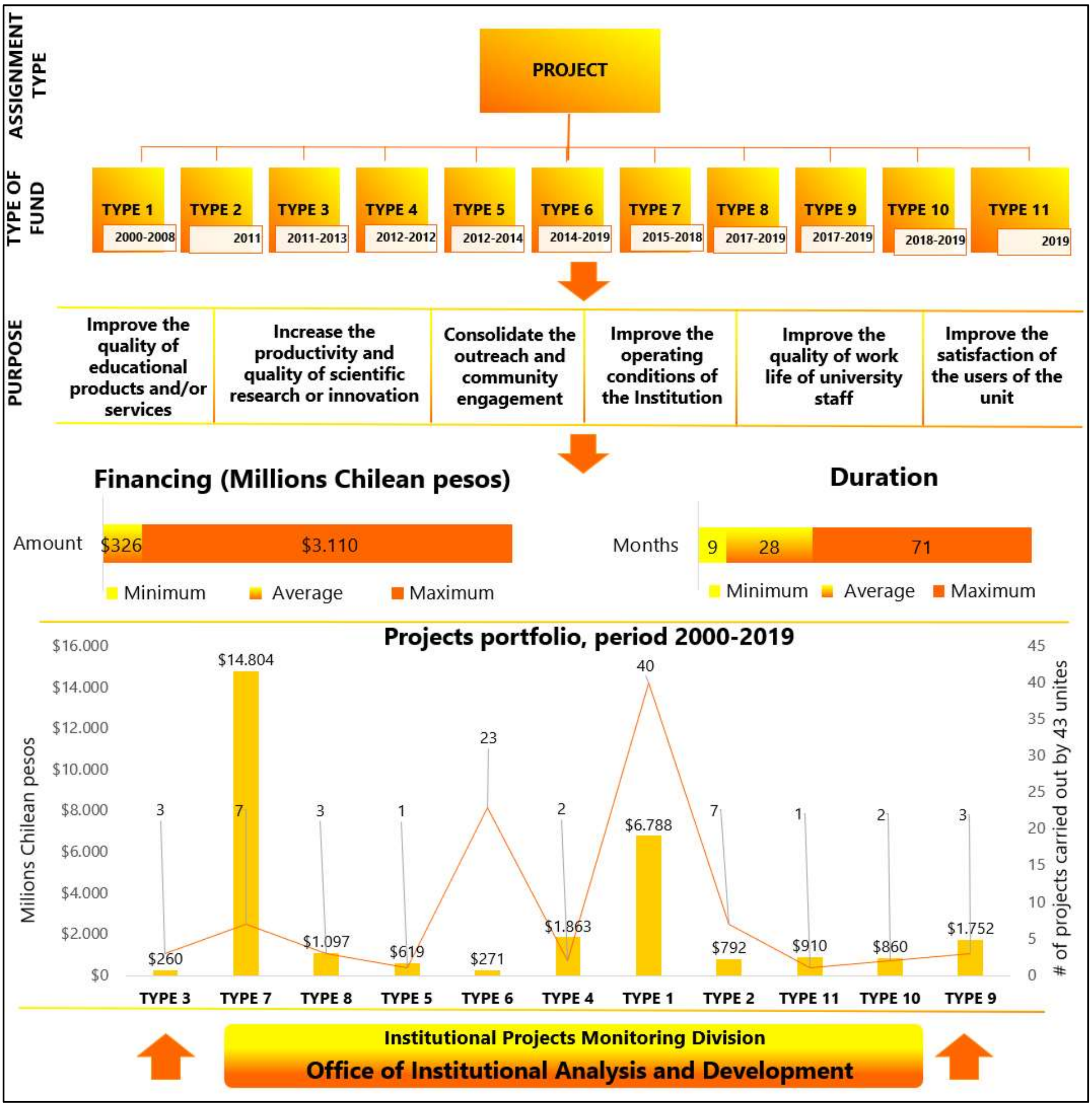

Figure 3 – Characteristics of projects included in the study

The NCh-ISO 21500:2013 for project management and quality management systems, and the Guide of the Fundamentals of Project Management –PMBOK® Guide– were compared. Both standards include the following groups of processes: Initiating, Planning, Executing, Monitoring and Controlling and Closing. They also include 10 knowledge areas: Integration, Scope, Schedule, Cost, Quality, Resources, Communications, Risk, Procurement, and Stakeholders. Other requirements include: relationship between organizational governance and project governance; project success and benefits management; project life cycle; role of the project manager; environmental factors and assets of the organization's processes; and adaptation of project objectives, being addressed in depth by the PMBOK® Guide (EIGP, 2016). The standard selected for the documentation of processes in this study was the PMBOK® Guide, considering that it is more thorough and common within the maturity models for the management of organizational projects.

Using those guidelines, the DSPI internal process map was updated to make the process groups, and their interactions, visible. As a result, the Initiating group was made up of four processes; the Planning group, one process; the Executing group, seven processes; the Monitoring and Controlling group, three processes; and the Closing group, one process. It was developed with the collaboration of the Chief of the DSPI and its staff.

The application of the instrument *"Diagnosis of compliance with quality requirements of the PMS"* included 41 questions in 7 dimensions: Organizational Context, Leadership, Planning, Support, Operation, Performance Evaluation and Improvement. The level of compliance was measured using the scale presented in Table 1. The instrument had a response rate of 67%.

Table 1 – Assessment scale for questionnaire of quality requirements of the PMS

Assessment Scale	Meaning	Description
5	Absolutely	Completely agrees with the statement. Has evidence and knowledge that supports said compliance.
4	In most cases	Largely agrees with the statement, but does not know some details. Has evidence and knowledge that supports the compliance.
3	Partially	Partially or moderately agrees with the statement. Has evidence and/or knowledge that supports the compliance.
2	It has made the effort	Incipiently agrees with the statement. Has some evidence and/or partial knowledge that supports the compliance.
1	Absolutely not	Does not agree with the statement. Does not have evidence and/or knowledge to support the compliance.
N.A.	Question does not apply	The consultation made was not related to the responding Unit. The Unit does not perform such actions, or it is not within its range of responsibilities.
N.S.	Does not know	The statement is unknown, and it is not possible to assess the degree of compliance.

The average results obtained indicate that the project staff perceived themselves as mostly complying with the requirements for quality management of a PMS, having evidence and knowledge to support their performance. The dimensions with the lowest average rating were: Performance evaluation –3.34–, Improvement –3.56–, and Support –3.7– (See Figure 4). The participants evaluated diversely and commented broadly regarding project management, possibly related to their experience, the role of them as participants, and the challenges addressed to achieve the promised results of the projects.

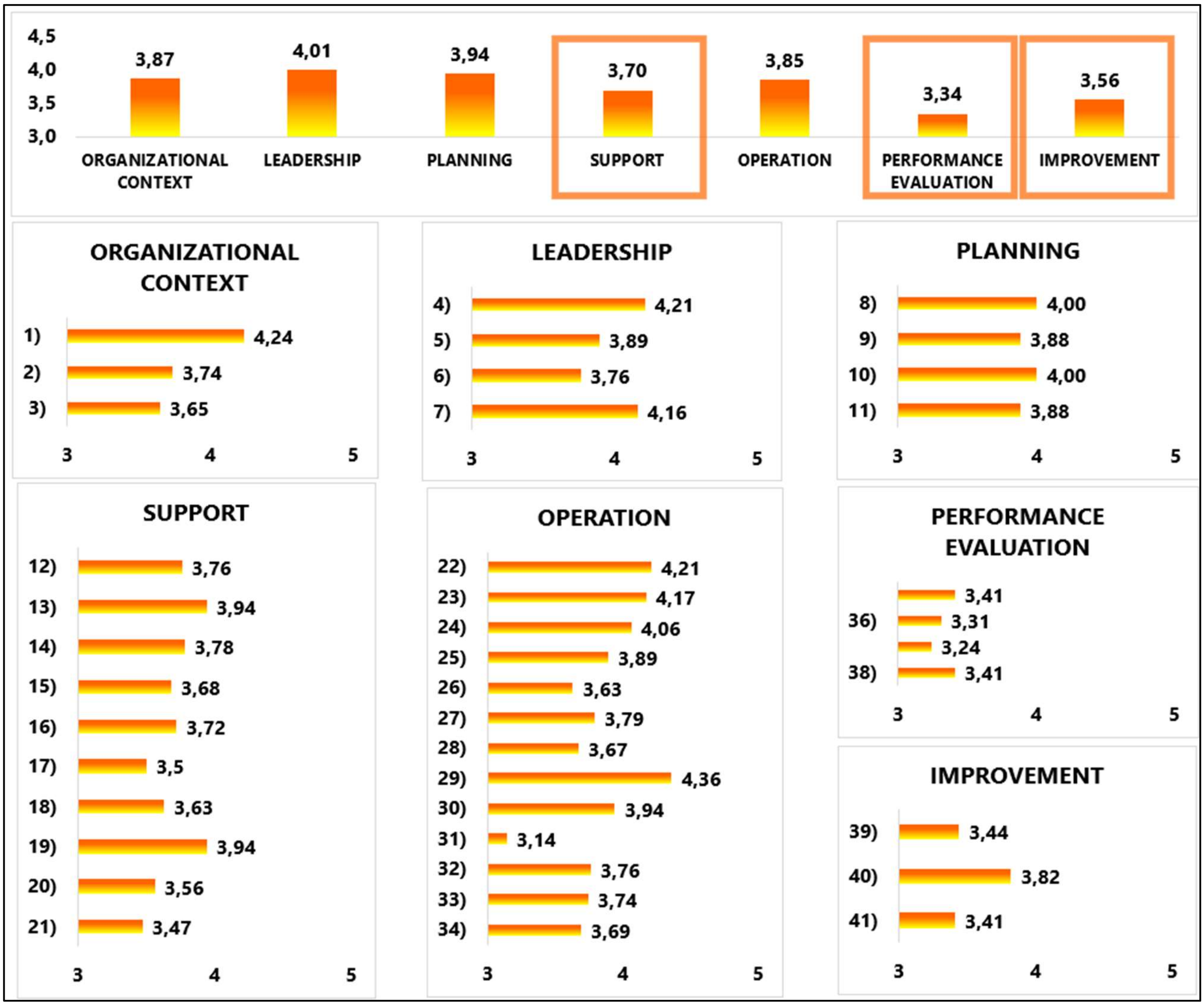

Figure 4 – Compliance with QMS requirements for a PMS

The percentage of *Does not know* responses (See Figure 5) varied by dimension. This might be due to low communication or a heterogeneous appropriation of information among the participants, thus reducing the effectiveness of the support processes provided by the DSPI and affecting the performance of the SGIC. This was reflected in administrative-financial emergencies, duplication of efforts, loss of learning, activities performed that did not generate value, and low engagement of some stakeholders.

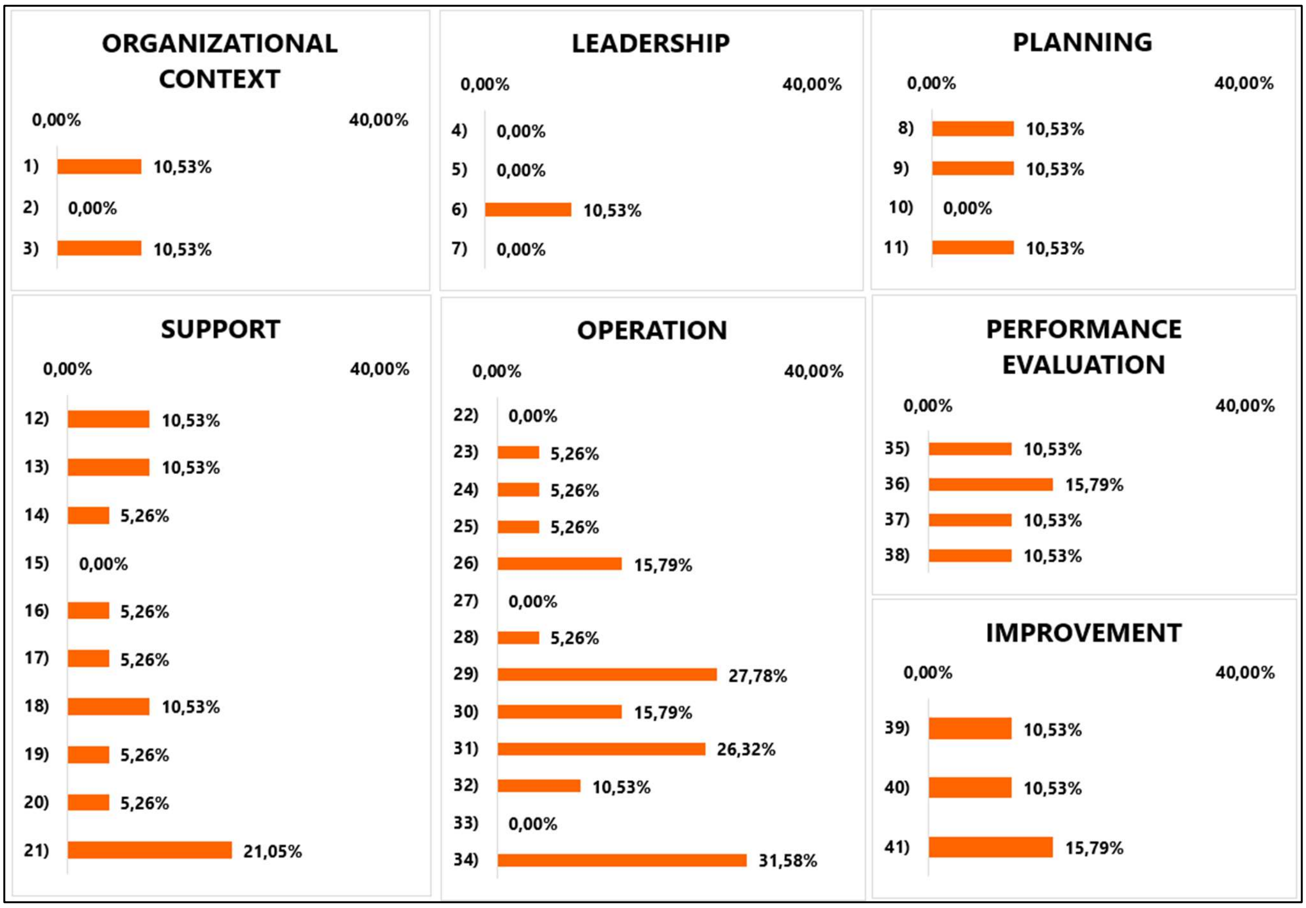

Figure 5 –Unfamiliarity of QMS requirements for a PMS

Note: Percentage of answers that declare ignorance of the question consulted

The elements of the standardized DSPI Project Management System, which include monitoring and control processes, are shown in the cause-effect diagram (Figure 6). Additionally, four procedures were elaborated and documented. This allowed the definition of the QMS scope for the PMS while following the SGIC guidelines and requirements while considering some elements of the maturity models. To ensure quality in the monitoring and control of projects, the documentation of processes focused on the requirements of MINEDUC and the CGR to be fulfilled.

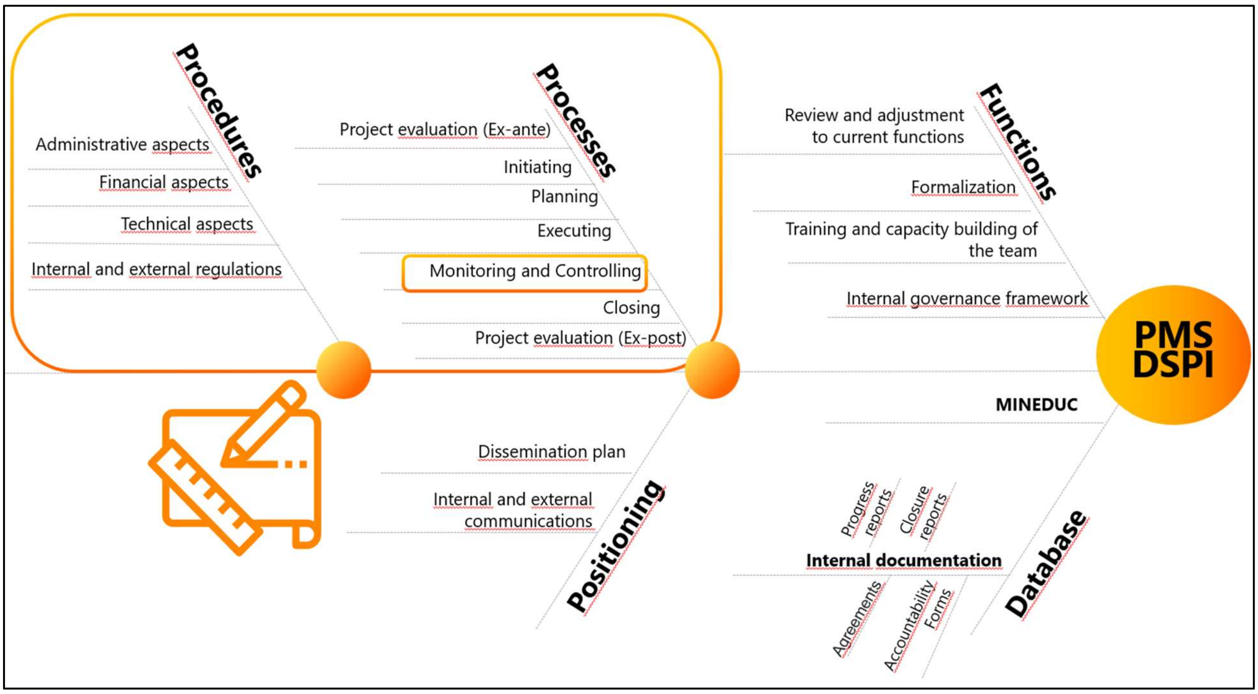

Figure 6 – Cause-effect diagram: Elements of the DSPI Quality Management System for the PMS

The interrelationships diagram (Figure 7) identified the interactions between process groups, processes, sub-processes, and activities. It also helped prioritizing processes to be documented, according to their precedence and dependency relationships. This was done based on the identified process group categories, e.g. *Monitoring and controlling*, which adjusted their names and categories to better represent the processes.

Based on the results of the questionnaire, the semi-structured interviews and the tools used, six processes were prioritized, and flowcharts were drawn: *Timeframe of the project; Control of A.I.U.E. resource spending; Financial accounts rendering; Collection and digitalization of documentation; Review and consolidation of project reports; and Monitoring of institutional projects under implementation.* For the last four processes, four procedures were written down.

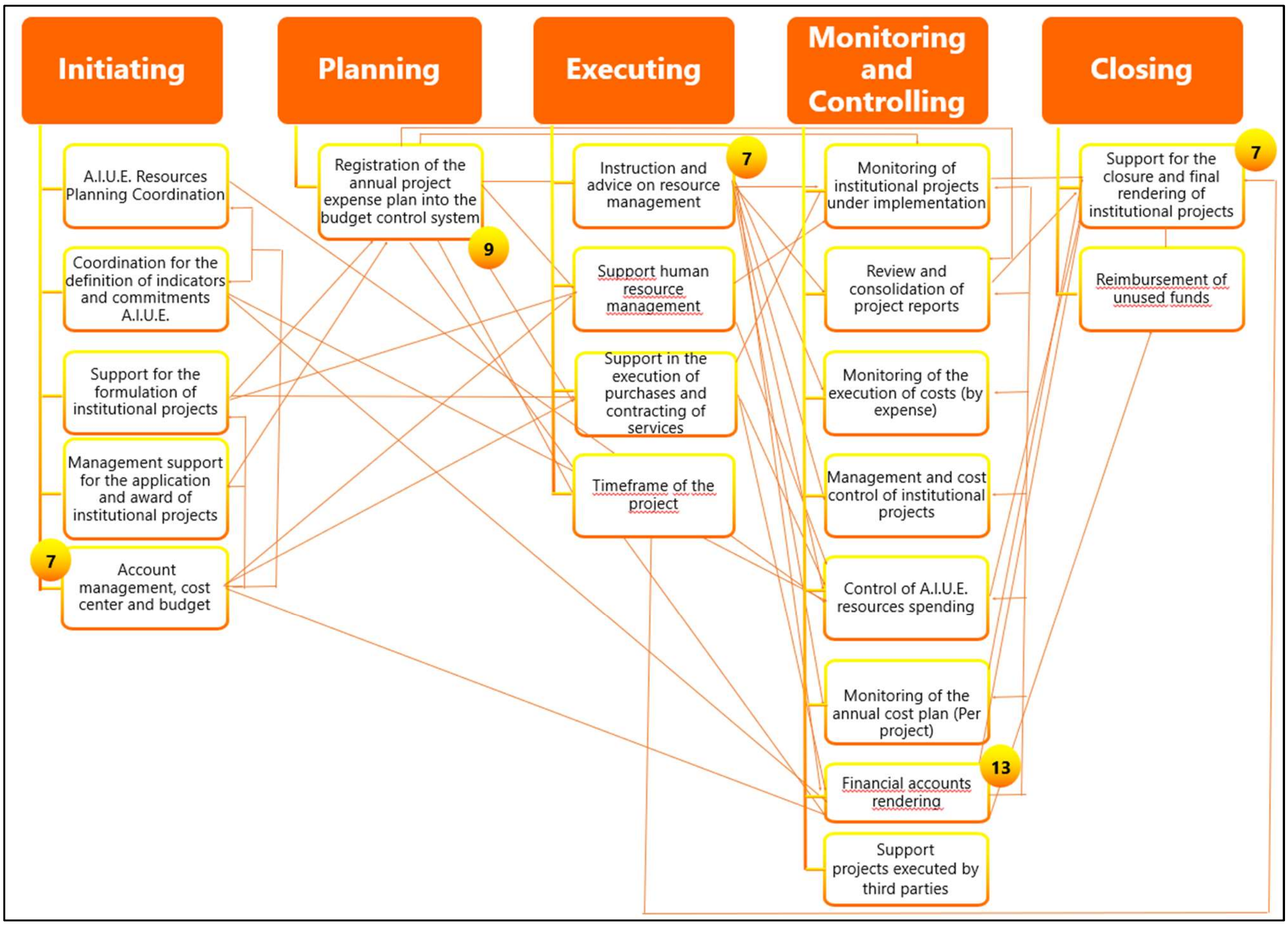

Figure 7 – Interrelationships diagram of selected processes

The identification and elucidation of the DSPI process groups, knowledge of their interrelationships and internal processes, drawing of flow charts, and procedures documentation had the purpose of improving the flow of work and communication within the internal and external stakeholders.

From the results, it was made clear that efforts of the DSPI had been concentrated on supporting the following knowledge management areas of the PMI: costs, resources and acquisitions; administrative-financial support and accounting reporting; monitoring of the start-up; execution and closure; and complying with legal and regulatory requirements. Other areas of knowledge of the PMI, such as scope, quality, communications, and risk and stakeholders, had been managed by the Director or person in charge of the project or proposal and his/her work team. This is similar to what Bonilla et al. (2019) found out "… there are different types of PMO, each one differs according to the importance and needs of the projects executed within an organization".

Quality assurement must be carried out throughout the life cycle of a project through monitoring and control. This is so we can supervise their progress, identify preventive actions, execute corrective actions, implement approved changes and recommend relevant actions, and to influence policies, processes and procedures of the institution (PMI, 2017).

Following the KPM3 maturity model guidelines, it is not necessary for levels to be met sequentially. This changes with the risk the organization is willing to take and the emergencies to be solved (Madero, 2018). Level 2 "Definition of common processes" is intended to achieve and repeat successful experiences in project management within the organization and is part of the QMS purposes. The DSPI has advanced in the design of its PMS using elements from levels 1, 2, 3, and 4, being the unit responsible for its implementation.

Considering the complexity of the PMS of the DSPI, several recommendations were made to comply with the five levels of the maturity model in the management of institutional projects with a QMS criteria. It was planned over a four-year horizon with an implementation cost of 45 174 250 Chilean pesos, equivalent to USD 55 401. This does not include: IT systems for project management, knowledge management, organizational practices, and project management techniques. Such recommendations are detailed below by level:

Level 1-Common Language. After the revision of ISO 9001:2015, ISO 21500:2013 and PMI, it was determined that the strategy and organizational enabler elements for DSPI were associated with the dimensions of context, leadership, and planning, which achieved the highest ratings when using the questionnaire *"Diagnosis of compliance with quality requirements of the PMS "*. Moving forward with this level requires strengthening the organizational enablers, e.g., elements that generate a "propitious environment for the specific processes of organizational project management to develop and be sustainable over time within the organization" (Sabogal and Castillo, 2014, p. 61). Among those are: the definition of project success criteria, training in project management, competence management, support for organizational culture, individual performance evaluations, and the creation of project management communities. These enablers are related to Support, Performance Evaluation, and Improvement dimensions.

Level 2. Definition of common processes. The progress and results in this level rely on: (i) time availability and dedication of the DSPI staff; (ii) definitions and agreements with internal stakeholders such as the Finance, Human Resources, and Procurement Coordination Departments; (iii) generation of internal capacities to standardize processes. For this, all processes identified in Figure 7 should be standardized. The gradual and progressive implementation of the QMS following the SGIC guidelines will allow improvements to be achieved by the DSPI at this level of maturity.

Level 3. Singular Methodology. Using practices already being used at the university, we must design common support processes for project management, meeting the demands of the MINEDUC and the

CGR in order to fulfill administrative-financial and accounting requirements. Considering the hybrid strategic planning of the institution, it is difficult to establish an institutional methodology for all institutional projects. The difficulty lies in the varying nature, complexity, and setting of each project.

Level 4. Benchmarking. The DSPI must evaluate the usefulness, and if necessary, adjust the instrument designed and used in this study. This will allow us to carry out progress measurement evaluations and perform data analysis considering significant elements to improve operations (Triana, 2018).

Level 5. Continuous Improvement. The standardization of prioritized processes, together with the operational planning of the DSPI allow advancing through this level. It requires defining performance indicators at the process level, and so, the DSPI must specify and measure the level of progress for each improvement objective defined in its annual planning.

It is expected that with the execution of these recommendations, the DSPI and the University shall move forwards in their maturity level for the organizational project management, and in the integration of its own QMS into the institutional SGIC.

CONCLUSIONS

Quality Assurance in the monitoring and control of institutional strengthening projects consists of supporting and ensuring compliance with standards, in terms of results, development, and operation within the organization. To reach such accomplishment, it is critical to comply with the national legal and regulatory requirements, as well as to have institutional support and commitment from senior management.

Although the assessment of quality requirements for a project management system presented average results with a high level of compliance for the DSPI, the data analysis showed a heterogeneous appropriation of information regarding institutional strengthening projects by some of the teams delivering results. The foregoing could cause inconveniences in the support operations provided by the DSPI, affecting the overall effectiveness and efficiency of the internal QMS, and thus, of the institutional SGIC.

The support processes for the management of institutional projects required the introduction of control points within their process groups: Initiating, Planning, Executing, Monitoring and Controlling, and Closing. The need to continue expanding the scope of the institutional PMS is reinforced, given the rigorous relationships and precedence between processes.

Regarding the PMI project management standard, the documentation of key processes in the monitoring and control of institutional projects revealed that the efforts of the DSPI were concentrated in: costs, resources and acquisitions, and partially, integration and schedule.

Updating the process map of the DSPI and the documentation related to monitoring and controlling processes of institutional projects made it possible to have a clear visual of the support processes led by the Unit. These processes must be periodically revised and updated as needed, to fulfill the requirements of the regulatory framework and university guidelines. The institutional SGIC provided a more robust structure to the operations carried out by the DSPI at the institutional level, allowing it to develop its own QMS based on the ISO 9001: 2015. There was a high level of coherence between its requirements and the elements of the Organizational Project Management Maturity Model, so it was integrated.

Given the priorities and requirements of the external regulatory framework of the University, the bulk of the first stage was focused on the second level of the organizational maturity model used. At Level 4, an instrument was designed to identify system gaps. Said instrument can be adjusted to include other elements considered relevant to be improved by the operations of the DSPI or similar organizations.

The PMS of the DSPI must be worked-on during all the levels of the organizational project management maturity model –From Level 1 to Level 5–. This will contribute to broadening the scope of the SGIC and improving institutional performance. Thus, the institution must guarantee the timely availability of organizational enablers to progressively improve the capacity of its processes and its internal work. It also requires having information systems in place for project management, knowledge management, and organizational and technical practices for project management.

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REFERENCES

Barreda, H. V. (2016), “Planteamiento estratégico en universidades de América Latina”, Revista Gestão Universitária Na América Latina, Vol. 9 No. 1, pp. 257–277. doi.org/10.5007/1983-4535.2016v9n1p257

Bonilla, B., Calderón, J., and Losada, J. (2019), “Diseño de una propuesta para la creación de una PMO en la Universidad de La Salle”, [Tesis de maestría, Universidad EAN], Colombia, Repositorio

EAN, available at: https://repository.ean.edu.co/bitstream/handle/10882/9581/BonillaByron2019.pdf;jsessionid=95F8AF21D8FA4ECCA1C03312C1AD91F1?sequence=1 (accessed 20 June 2020).

Calderón, J. (2012), "Propuesta para la creación de una Oficina de gestión de proyectos (PMO) en FONADE", [Tesis de maestría, Universidad EAN], Colombia, available at: https://repository.ean.edu.co/bitstream/handle/10882/3840/CalderonJose2013.pdf?sequence=3 (accessed 12 May 2020).

Castellanos, T., Delgado, J. and Gallego, J. (2014), "Análisis comparativo entre los modelos de madurez reconocidos en la gestión de proyectos", [Tesis de maestría, Universidad de San Buenaventura Cali], Colombia, available at: http://bibliotecadigital.usb.edu.co/bitstream/10819/2163/2/1131056_1131054_1131185_ANEXO_Cap%C3%ADtulo.pdf (accessed 18 May 2020).

Celis, S., Gaete, R., and Baeza, S. (2021), "Análisis de Planes de Fortalecimiento a 10 años, Universidades Estatales (Informe I, BIRF 8785-CL)", Ministerio de Educación de Chile, http://dfi.mineduc.cl/usuarios/MECESUP/File/2021/PLANFUES/permanent/4-Informe-1-Analisis-de-Planes-a-10-anos-UES.pdf (accessed 13 March 2022).

Contraloría General de la República. (2021), "Propósitos, funciones y estructura", https://www.contraloria.cl/web/cgr/que-hacemos (accessed 19 January 2021).

Diez, E., García Martínez, R., Pytel, P., Rodríguez, D., Lacabanne, M., Leonardis, L., Martins, S., and Cartannilica, A. (2012). "Aseguramiento de la calidad para proyectos de explotación de información. XIV Workshop de Investigadores En Ciencias de La Computación", pp. 212–216. http://hdl.handle.net/10915/18605

Escuela internacional de gestión de proyectos-EIGP, (2016), "La Norma ISO 21.500:2012", Salamanca. España.

Espinoza, O., López, D., González, L., and Pulido, S. (2020). "Calidad en la universidad. LOM Ediciones", available at: https://www.researchgate.net/publication/338431356_Calidad_en_la_Universidad#fullTextFileContent (accessed 20 March 2020).

García Aracil, A. (2013), "La planificación estratégica en las universidades públicas en España: un análisis de sus objetivos", Aula, 19, pp. 111–132. doi: 10.14201/14689.

Hernández, R., Fernández, C., and Baptista, M. (2010), "Metodología de la Investigación", McGraw-Hill / Interamericana Editores (Ed.), Quinta Edición, México.

Instituto Nacional de Normalización. (2018), "NChISO21.001:2018. Sistemas de gestión de calidad para organizaciones educativas", Chile.

International Organization for Standardization, (2015), "ISO 9001:2015 Quality management systems. Requirements". Retrieved from www.iso.org

Jara, G. (2019), "Estandarización de procesos para el posicionamiento de la marca UFRO de acuerdo al sistema de gestión de la calidad de la Dirección de Comunicaciones", [Tesis de maestría, Universidad de La Frontera], Temuco, Chile.

Labrada, S. and López, H. (2010), "Valoración de la gestión de proyectos en empresas de Bogotá: nivel de madurez en gestión de proyectos", Revista Escuela de Administración de Negocios, (69), pp. 60–87. doi: 10.21158/01208160.n69.2010.517

Lemaitre, M. J., Maturana, M., Zenteno, E., and Alvarado, A. (2012), "Cambios en la gestión institucional en universidades. a partir de la implementación del sistema nacional de aseguramiento de la calidad: la experiencia chilena. Calidad en la Educación [online]", No. 36, pp.21-52, avalaible at: http://dx.doi.org/10.4067/S0718-45652012000100001 (accessed 20 August 2020).

Madero, A. (2018), "Evaluar la madurez organizacional en gestión de proyectos en una universidad pública", [Tesis de Maestría, Universidad Tecnológica de Bolívar]. Colombia. https://biblioteca.utb.edu.co/notas/tesis/0073031.pdf

Ministerio de Educación. (2020), "Reporte Subsecretaría de Educación Superior", [Responde AJ001P-1657188 María José Painén (Transferencias DFI)-ajustada].

Pérez, L. and Shek, I. (2014), "Evaluación de la gestión en las organizaciones. Conceptos y experiencias", Revista Soluciones de Postgrado, 6(12), pp. 45–65, avalaible at: https://revistas.eia.edu.co/index.php/SDP/article/view/59 (accessed 14 August 2020).

Project Management Institute, Inc., editor. (2017). La guía de los fundamentos para la dirección de proyectos (Guía del PMBOK). 6° Edición. Pennsylvania, EE.UU. Pág 4.

Reich, R., Fernández, V., Machuca, F. and Saavedra, A. M. (2010), "Nueva Arquitectura para el Aprendizaje, http://dfi.mineduc.cl/usuarios/MECESUP/File/2010/publicaciones/NuevaArquitecturaAprendizaje2010.pdf

Reyes, S., Canelon, J., Olaya, S. and Yzquierdo, R. (2018), "Análisis de la gestión de proyectos de investigación realizados en la Universidad Central del Este: una primera aproximación desde el estándar PMBOK. UCE Ciencia. Revista de postgrado, 6(3), avalaible at: http://uceciencia.edu.do/index.php/OJS/article/view/147/140

Sabogal, J. and Castillo M. (2014), "Grado de madurez en la gestión de proyectos de las empresas constructoras de Bogotá, D.C.", [Tesis de especialización en gerencia de obras, Universidad Católica de Colombia]. Repositorio RIUCaC. https://repository.ucatolica.edu.co/bitstream/10983/2134/1/GM_GP_Empresa_constructora_S%C3%A1nchez_Foliaco_Ingenieros.pdf (accessed 25 July 2020).

Solarte, L. and Sánchez, L. (2014), "Gerencia de proyectos y estrategia organizacional: el modelo de madurez en Gestión de Proyectos CP3M© V5.0", Revista de Ciencias Administrativas y Sociales, Vol. 24 No. 52, abril-junio, 2014, pp. 5-18, Universidad Nacional de Colombia

Solarte, L. and Sánchez, L., (2014), "Gerencia de proyectos y estrategia organizacional: el modelo de madurez en Gestión de Proyectos CP3M© V5.0." INNOVAR. Revista de Ciencias Administrativas y Sociales, Vol. 24 No.52, pp.5-18 ISSN: 0121-5051. https://www.redalyc.org/articulo.oa? (accessed 31 de May de 2020].

Srinivas, A., Suresh. K. and Aithal P. (2015). "Strategic Planning in Higher Education Institutions: A Case Study of Sims - Vision 2025", International Journal of Educational Science and Research (IJESR), 5(2), 29–42. http://www.tjprc.org/view-archives.php?year=2015_26_2&id=49&jtype=2&page=1 (accessed 20 July 2020).

Sthioul, A., González, R., Rifo, M. and Torralbo, F. (2018), "¿Un cuarto estamento universitario?: Percepción de grupos directivos y académicos de las universidades estatales sobre este nuevo equipo de profesionales en la gestión universitaria, Serie Evidencias (Vol. 39). Biblioteca Digital Mineduc. Chile.

Summers, D. (2006), Administración de la calidad, Pearson Universidad, México.

Triana, S. (2018), "Modelo para el diagnóstico de madurez en la gestión de proyectos para mipymes de mantenimiento del sector metalmecánico en la localidad de Kennedy". Repositorio Instituciona UMNG. Universidad Militar Nueva Granada. 2018. http://hdl.handle.net/10654/18140 (accessed 15 July 2020).

Universidad de La Frontera. (2014), "Resolución Exenta 5379. Crea División de Seguimiento de Proyectos Institucionales, modifica D.U. N° 017 de 2006 y 119 de 2008".

Velez García, S., Zapata cortes, J. y Henao Rosero, A. (2019) "Gestión de Proyectos: origen, instituciones, metodologías, estándares y certificaciones", Entre Ciencia e Ingeniería, 12(24), pp. 68-76. doi: 10.31908/19098367.3818.

Villar, V. (2013), “Integrando los proyectos con la estrategia organizacional. Sinergia e Innovación, 1(10)”, Repository Universidad Peruana de Ciencias Aplicadas, Perú, http://revistas.upc.edu.pe/index.php/sinergia/article/view/81 (accessed 05 July 2020).

Controlling industrial Measuring and Monitoring Equipment status through EWMA and I-MR charts

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Purpose – The main goal of this work was to develop a methodology to monitor the state of measuring and monitoring equipment (MME). The purpose of this method was to verify if a given MME remains fit for use and to ascertain the need to anticipate the next calibration or verification period, if any deviation happens. This method is based on the analysis of the stability of the instrument with regard to the measurement error and its ability to measure the target value. This article uses control charts, namely EWMA (Exponentially Weighted Moving Average) and I-MR (Individuals-Moving Range) charts.

Design/methodology/approach – Verification data available from a company dedicated to the production of cork stoppers was used. Through a set of measuring instruments, which integrate the organization production process, these two types of control charts were built, for each significant verification point of these instruments.

Findings – It was found that these charts combined bring important information about the measuring equipment status. The EWMA charts made it possible to understand if the equipment is measuring above or below the desire value. The I-MR charts allow to understand if, even though there is an increase in the measurement error, these errors are still far from exceeding the acceptance criterion (AC), verifications can be less frequent or, if the contrary, monitoring should be frequent due to the average error being close to the AC.

Originality/value – The proposed approach allows taking decisions about the need to reduce or increase the interval between calibrations/verifications in order to reduce quality costs.

Keywords: Calibration and Verification, EWMA, I-MR, Monitoring and Measuring Equipment.

INTRODUTION

Nowadays, and regardless of the activity sector, product quality and customer satisfaction are the main focus of an organisation. Consequently, companies are looking for reliability in their measurement systems, since measuring and monitoring equipment (MME) is used to assess product conformity and to control and monitor production processes, making the management of this equipment a crucial factor in organisational performance.

In this way, and in order to ensure the reliability of measurements, measuring instruments must be calibrated at appropriate intervals to guarantee that the instrument is in a state of conformity with the requirements for its intended use.

Over time, MMEs undergo changes in their metrological properties, which may be caused by the use and ageing of the equipment itself, as well as by unforeseeable situations, such as falls or shocks caused by improper use of the equipment. In this sense, the need to monitor these devices, which may suffer damage or premature deterioration between consecutive calibrations or verifications, arises in order to prevent it from being used inappropriately.

The objective of this paper is therefore to present an approach for evaluating the status of MME, based on the analysis of the stability of the measuring equipment. For this purpose, control charts, namely EWMA (Exponentially Weighted Moving Range) and I-MR (Individuals-Moving Range) charts are used. Through the analysis of these graphs, it is intended to verify if a given MME remains fit for use and to ascertain the need to anticipate the next calibration period.

The paper is organised as follows. The second section presents a literature review followed by a section that describes the methodology used for the development of the approach. Subsequently, the results obtained and the main conclusions are presented.

LITERATURE REVIEW

Calibration and Verification

Calibration is a confirmation process used to verify the operational status of any measuring instrument and to characterise its metrological properties (Morello and Paciello, 2014). De Capua, De Falco, Liccardo and Morello (2005) argue that, in general, the aim of the calibration process is to reduce occurrences outsider the tolerance limits to an acceptable level, taking into account the outlined quality objective.

The calibration results must be approved against the Acceptance Criterion (AC) which, in practice, represents the maximum error that can be accepted for the use of the equipment. This criterion may be established by each organisation, according to their processes and the use given to each piece of equipment, or may already be defined by a reference document (a standard, for example). Thus, after a given equipment is submitted to the calibration process, its approval shall be made by checking compliance with the following inequality in all calibration points:

$$|AC| \geq |Error| + |Uncertainty|$$

On the other hand, and according to the International Metrology Vocabulary (2012) verification is the "provision of objective evidence that a given item meets specified requirements" (page 29). This means that the verification process seeks to find out if there has been any significant change in the characteristics of an equipment during its period of use, since the last calibration, ensuring the credibility of the measurements. This process allows, therefore, to verify if a given instrument is working within the tolerance limits.

Although they cannot be confused, these two types of processes, calibration and verification, seek to ascertain whether the equipment is operating within tolerance limits, and the main difference between them lies in the complexity associated with each one. If, on the one hand, in calibration, several measurements are taken for the same test point, which allows the calculation of uncertainties, on the other hand, in verification, a single measurement is taken for each test point. Furthermore, while the calibration process must be carried out internally or by an accredited laboratory and requires the issue of a certificate, the verification can be carried out by the operator or technician responsible for the equipment and only a documented record is necessary. Finally, the calibration test points may or not coincide with the verification test points.

Control Charts

Statistical process control uses techniques to monitor the behaviour of processes in relation to their parameter specifications in order to control variation, which may be inherent to the process (common causes) or caused by external agents (special causes), and to determine whether the process is capable of producing within pre-defined specifications.

Among the tools used in statistical process control, control charts are considered the most technically sophisticated practice (Stuart, Mullins and Drew, 1996).

Control charts are applied with the purpose of analysing process stability and consist of a graphic representation of the evolution, over time, of a statistic relative to a given quality characteristic. Thus, a given process is under statistical control if the probability distribution, which represents the characteristic, remains constant over time, and out of statistical control if there is any change in that distribution.

This tool is essential for monitoring processes since its application enables relevant information to be obtained to control processes' effectiveness. In other words, through control charts it is possible to distinguish the variability inherent in the process from atypical situations caused by sporadic causes.

I-MR Charts

When the characteristics of the process make it impossible or impractical to take samples, it is necessary to use individual observations (n=1) and in these situations one of the types of control chart that is suitable is the Individual and Moving Range chart (I-MR).

This chart is intended to monitor and detect changes in the process average through the analysis of the consistency of individual observations of a given characteristic.

For a correct application of this chart, it is necessary to verify some assumptions regarding the data used in their construction, including independence, randomness and normality of the data. This means that, the data used must follow a Normal distribution so that the conclusion coming from the analysis of these charts are reliable (Scouse, 1985).

EWMA Charts

The EWMA charts, as well as other special control charts, arose with the need to increase sensitivity in the detection of special causes, without causing great impact on costs (Scouse, 1985). In addition, they were created to respond to some shortcomings of the Shewhart charts, associated with low efficiency to detect small changes in process parameters and lack of robustness regarding the assumptions underlying their implementation, namely the independence and normality of data (Scouse, 1985).

EWMA charts are recommended when it is intended to detect small changes in the process mean, since the values used incorporate information from past observations and not just from the most recent one. The most recent observation is assigned a weight λ (weighting factor), and past observations a weight $1-\lambda$. Therefore, the EWMA chart allows for an exponential decrease in the weight of observations taking into account the age of the data (Fallah Nezhad and Akhavan Niaki, 2010). It is important to mention that for lower λ values the chart detects small variations faster, making older/historical data carry more weight. On the other hand, conversely, higher λ values make the last observation weigh less (Claro, Costa and Machado, 2007).

This type of charts can be applied in situations where the process is monitored by individual observations, i.e. from a process of sequential samples of size n=1(Claro, Costa and Machado, 2007).

In the context of MMEs monitoring, and despite the importance of this equipment for organisational performance, there is little literature that explores and proposes methods/approaches to control MMEs' behaviour over time.

Among the existing literature, related to calibration and verification, it is worth mentioning Oliveira and Jesus (2015), who propose a modified SWOT analysis to select the most appropriate calibration interval determination method and Portella and Frota (2006), who present a method for calculating calibration intervals. On the other hand, and more related to the subject of this paper, Baldo, Probst e Dewulf (2020) use control charts to evaluate data from the measurement process under study, in order to understand whether the process is predictable or not, and Gaber (2021) uses intermediate verification results and control charts to monitor the need for equipment recalibration. Although in these last two cited papers the authors use control charts, their applications are different when compared to the present paper. On the one hand, Baldo, Probst Dewulf (2020) use this tool to evaluate the measurement process and not specifically the behaviour of the measurement equipment and, in addition they do not use EWMA nor I-MR charts. Gaber (2021) despite presenting a similar goal to this paper, i.e., to establish a method that allows the analysis of the stability of the measuring equipment, and consequently, to adjust calibration/verification intervals, does not use EWMA charts and the sample size is not n=1.

Therefore, the lack of literature in this area points to the importance of this paper, which aims to present an approach for assessing the status of MMEs, using control charts with a sample size n=1.

RESEARCH METODOLOGHY

Although control charts are usually used in process monitoring, in this work it is intended to use this tool to analyse the condition of measuring and monitoring equipment, in order to determine the need to intervene on them.

In this sense, and with the aim of understanding whether the use of control charts – EWMA and I-MR – would satisfy the intended objective, a case study was carried out, using data from the measuring and monitoring equipment of a company dedicated to the production of cork stoppers.

The study included 9 pieces of equipment – 2 hygrometers, 2 comparison tables, 2 scales and 3 callipers – which are part of the production process of the organisation. These equipment are subject to monthly internal checks, in the case of the hygrometers, and quarterly in the case of the other equipment.

The data collected includes the AC of each piece of equipment, the test points and the verification results obtained between the years 2015 and 2020.

Hygrometers have an AC of 0,67% and a verification test point of 6,00%. For the scales, the AC can vary and can assume the values 0,83g or 0,33g, depending on the scale. As for the verification test points, these are 1,00g, 5,00g, 10,00g, 100,00g and 1000,00g. Finally, the callipers and the comparison tables have an AC of 0,07mm and their verification test points are 5,00mm, 15,00mm, 40,00mm and 50,00mm.

With the collection of these data, the types of control charts mentioned above were created for each test point of each equipment that makes up the sample.

On the one hand, and resorting to the measuring results obtained in the verifications, it was intended, through the EWMA charts, to understand if a given measuring equipment is measuring above or below the desire value, considering as target value the true value of the reference standard used in the verification. On the other hand, and using the errors obtained in each measurement instead of the measurement results, it was intended, using the I-MR charts, to observe the evolution of the measurement error over time. By using the errors as variable, instead of the value directly measured by the equipment, it is possible to add the AC to the graphs and, consequently, to understand if it is being respected and if there is slack.

Besides the graphs do not give the same information, the EWMA graph has the advantages of being able to detect small variation in the average more quickly and, in addition, the data normality is not mandatory.

This means that, with the construction of these graphs, the aim is to understand if, in real time, they would bring relevant and sufficient information about the behaviour of the instruments, that is, to understand if the MME is stable and if there is a need to anticipate the next calibration period.

RESULTS

As previously mentioned, the graphs were applied to all the test points of the equipment in the study. However, this section presents the results obtained in three equipment, namely for one of the points of each of them.

The graphs corresponding to the 15,00mm point of one of the comparison tables, the 5,00mm point of one of the callipers and the 1000,00g point of one of the scales analysed are presented. These equipment and their respective landings were selected because they represent different situations, which consequently allow for more objective conclusions to be drawn. It is important to note that whenever these graphs are applied, a prior analysis study should be carried out in order to calculate the mean and standard deviation in a stable situation. In this case, and since data from historical record of a company was used, this pre-study was not possible and the mean and standard deviation were calculated with a sequence of values that showed no assignable causes.

To construct the EWMA chars it was necessary to define their parameters, namely, the values of the constants λ and k, which have the ability to influence efficiency measures, such as the type I error. The type I error (α) corresponds to the occurrence of false alarm, i.e., when the graph determines that the process is out of control when in fact it is not. This means that α is the probability that a point is outside the control limits due to random causes.

That said, based on the knowledge that, in general, α decreases exponentially as k increases, and with the aim of minimising α, it is recommended that EWMA plots be constructed with k values between 2,5 and 3 (Scouse, 1985). Considering this, and in order to detect small variations faster, a lower λ equal to 0,1 and a k of 2,7 were selected, which provides the same level of confidence as the Shewhart charts.

Comparison Table

For the comparison table, the EWMA and I-MR charts show a stable situation, since in both the values are within the control limits (no other criteria were used for I-MR charts).

The EWMA chart (Figure 1) shows that the values have been approaching the upper control limit, without exceeding it. This information can be justified by the fact the average error is small (equal to 0,002mm). By analysing the I-MR charts (Figures 2) it can be seen that the errors obtained in the measurements performed by the instrument, besides being within the control limits (UCL – upper limit control; CL – central line; LCL – lower control limit), when compared with the AC, are still distant, which allows concluding that even if in the I-MR plots the values exceed the control limits in the next observations, there is still a significant margin between the errors and the respective natural variability limits and the AC. Consequently, the calibration/verification period could be increased with some assurance that the AC will not be exceeded. In this sense, and using methods for defining calibration/verification intervals, it can be seen that, the method of adjusting the interval based on the last three calibration suggests an increase of 0,3 months from the current verification interval and the method of adjusting the interval based on the drift suggests a period of 21 months, which is a significant increase compared to the current interval of three months (Oliveira and Jesus, 2015).

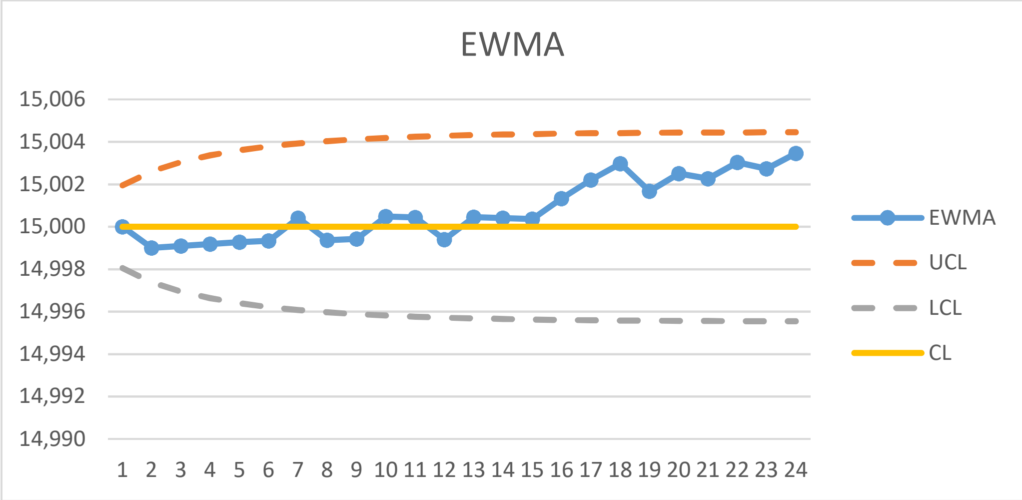

Figure 1 – Comparison Table EWMA chart (target value = 15,00mm)

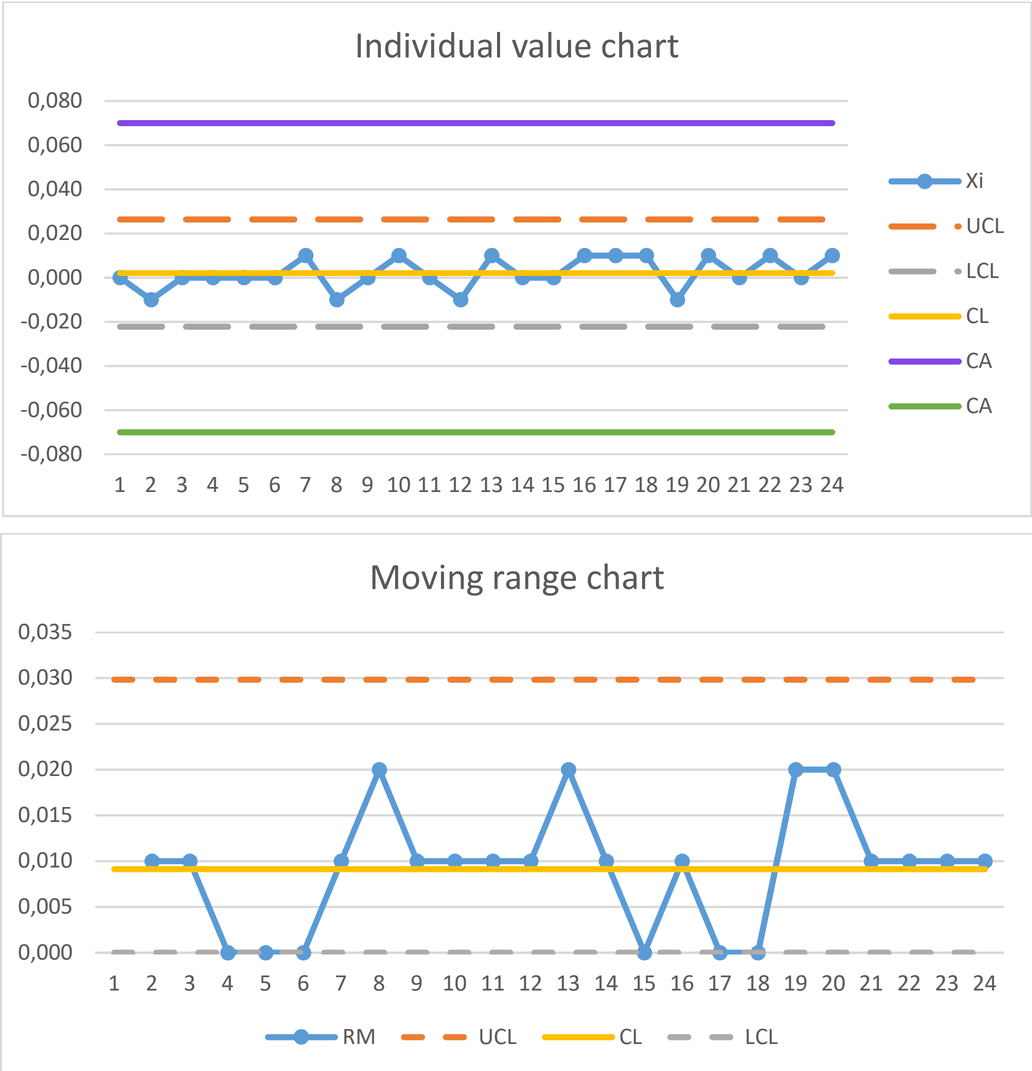

Figure 2 – Comparison Table I-MR charts

However, in this case some care must be taken in the interpretation of the I-MR charts since an analysis of the data, through the Kolmogorov-Smirnov test, revealed that they cannot be considered to follow a Normal distribution due to the little variability present (i.e., there are several identical values). Consequently, in this case, the EWMA chart is more reliable. To understand whether the error remains stable over time, instead of using the true value of the reference standard for the target value, it was considered the mean in a stable situation (or the sum of the standard value and the mean error) and a new chart was built (Figure 3).

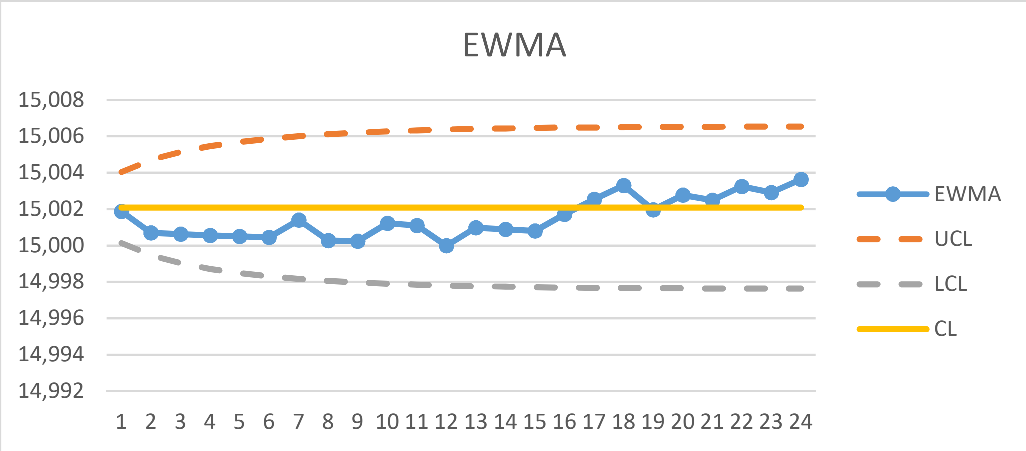

Figure 3 – Comparison Table EWMA chart (target value = 15,002mm)

Observing the Figure 3, it can be concluded that this is a stable situation, where all values are within control limits.

Calliper

Looking at the calliper charts it can be seen that in all of them there are points outside the control limits.

On the one hand, the EWMA chart (Figure 4) shows that the equipment has been measuring below the target value, since the last values are below the control limit. Complementing what is observed in that graph, the I-MR charts (Figures 5) show that the errors of the last observations besides being below the control limit, are close to the AC. This may suggest the need for special attention with this equipment since it may become unfit for use. Hence, it should be noted that this information was obtained through the control charts, and that the comparison made by the company between the error and the AC would not be sufficient to achieve this conclusion, which reinforces the usefulness of applying these charts to evaluate the behaviour of this equipment.

It is also important to mention that, in this case, and comparing the EWMA and the I-MR charts, the I-MR graphs seem to register the need to pay attention to this equipment earlier. This may mean that, for the EWMA chart not be making this detection earlier, the variation is significant. One solution to increase the capacity of this chart to detect significant deviation, as mentioned above, would be to increase the value of λ.

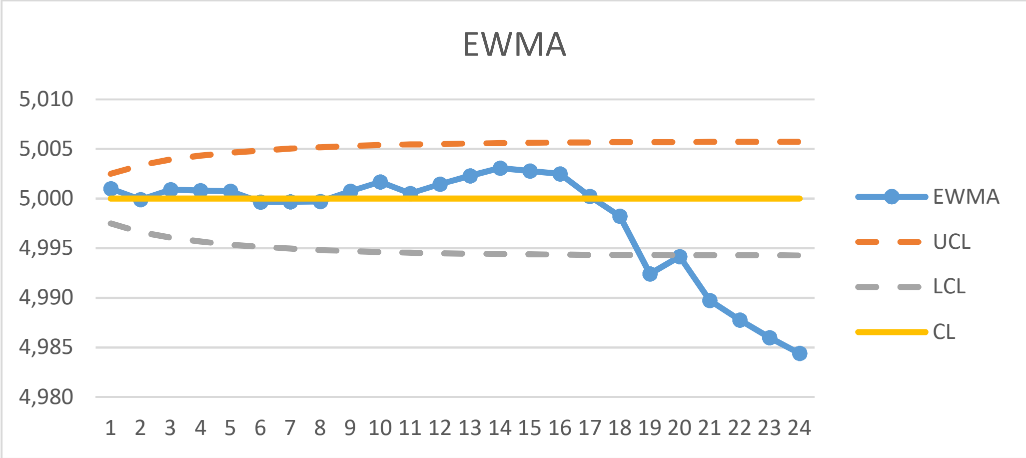

Figure 4 – Calliper EWMA chart (target value = 5,00mm)

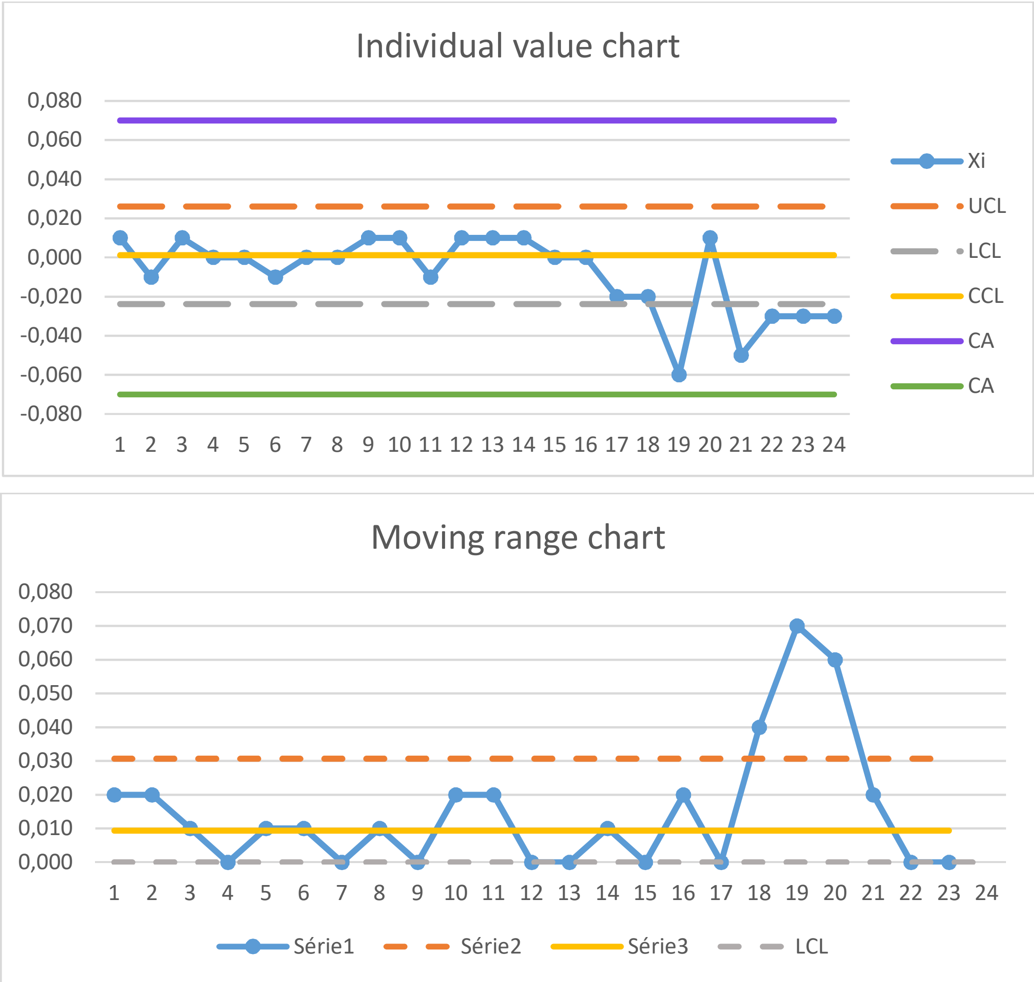

Figure 5– Calliper I-MR charts

For this equipment, as in the case of the comparison table, a normality test was performed and it was found that the data cannot be considered to follow a Normal distribution. Once again, the reason seems to be the little variability associated with the observed data.

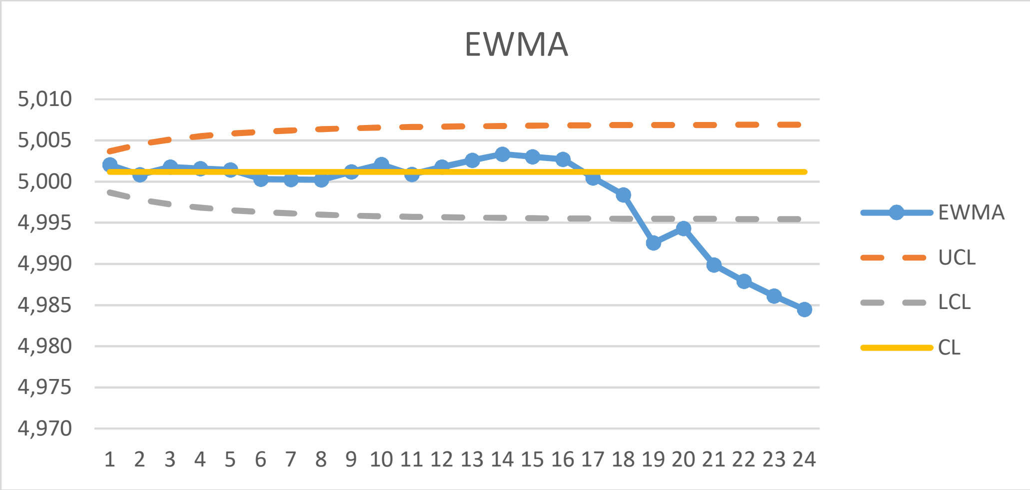

Figure 6 – Calliper EWMA chart (target value = 5,001mm)

Such as in the case of the comparison table, a new EWMA chart was built considering a target value equal to the mean of the stable situation. The chart depicted in Figure 6 shows from observation 19 that the error increases.

Scale

Analysing the EWMA graph (Figure 7) and the I-MR graphs (Figures 8) of the analysed scale, it is possible to conclude that this is a situation out of statistical control and, in addition, this scale is no longer fit for use as shown in the I-MR charts. It is also important to note, by observing the graph of individual values, the position of the AC in relation to the lower control limit. The AC associated with this equipment is above this limit, which in itself is a warning that this test point requires attention.

On the other hand, when analysing the capacity index, that is, the capacity to comply with the requirements of a given specification, it can be concluded that although capacity exists, there is little slack. Considering $Cp = \frac{T}{6\sigma}$, where T is the interval between the upper and lower AC and σ is the standard deviation obtained in a stable situation, a Cp of 1,23 was obtained. Taking into account this value, it can be concluded that there is a need for frequent control of this equipment. Furthermore, and emphasising the last three observations, they indicate the need to adjust the equipment.

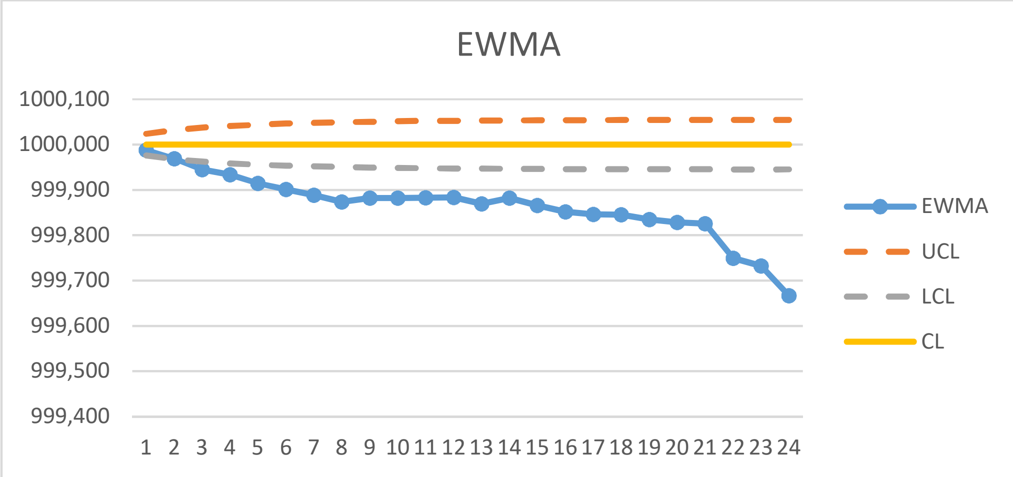

Figure 7 – Scale EWMA chart (target value = 1000,00g)

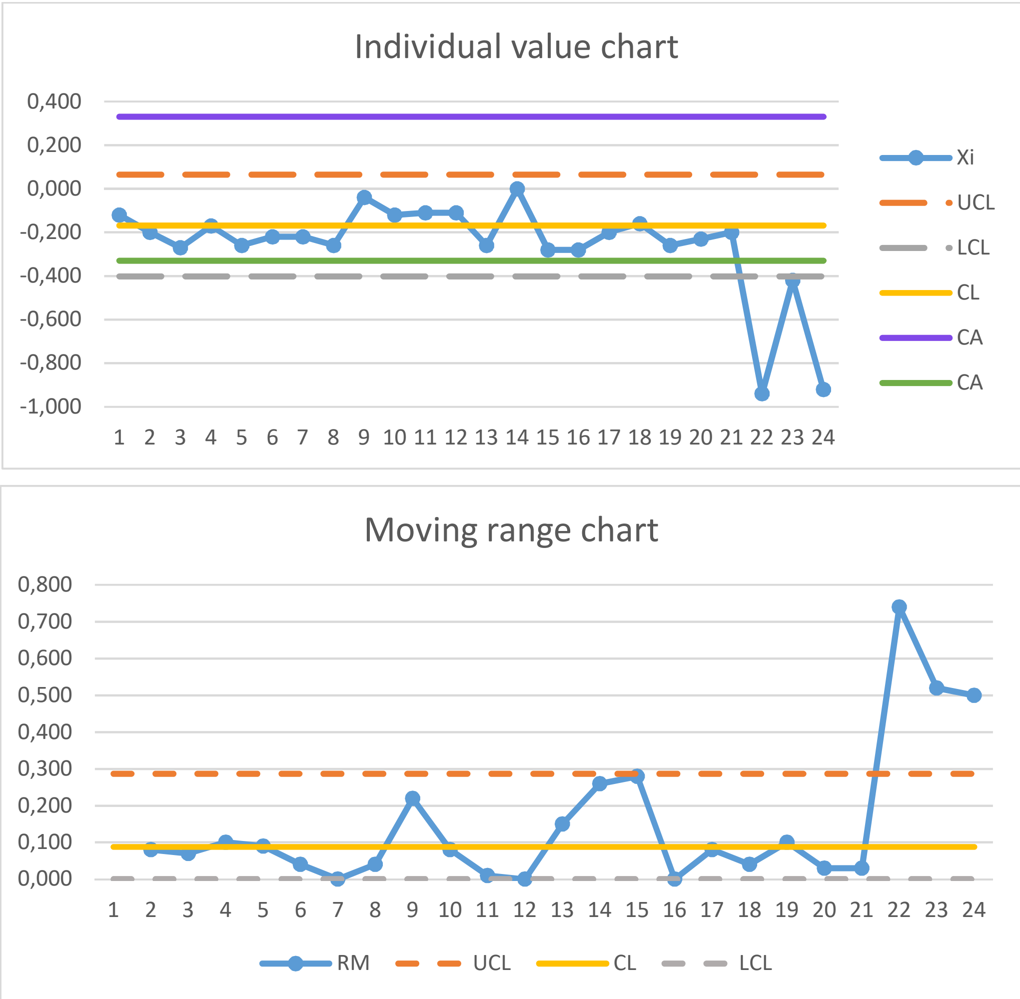

Figure 8 – Scale I-MR charts

In the case of the scale, the graph of Figure 7, where the target value corresponds to the measuring level of the equipment (1000,00g), shows that, due to the high average error, the values are below the control limit from the beginning.

Although the verification data follows a Normal distribution (in a stable situation), unlike the data from the comparison table and the calliper, an EWMA chart was also constructed with a target value equal to the average of the observations from a stable situation. This chart shows the natural variability limits around the mean of the measurements. Consequently, the chart allows detecting the presence of non-random variation in relation to the mean error initially associated with this equipment.

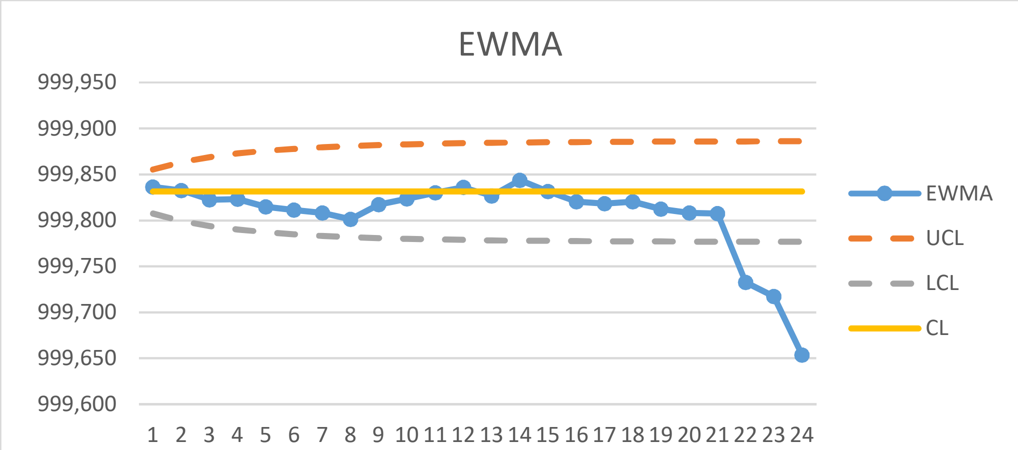

Figure 9 – Scale EWMA chart (target value = 999,831g)

The EWMA graph (Figure 9) shows that the measurements made by the equipment are within control limits until the second-to-last observation, indicating that, despite being high the error is randomly distributed. Considering the last three observations, however, the chart indicates that the equipment did not remain stable.

Although in this paper only three cases of the study have been exposed in detail, the remaining equipment also contributed to the achievement of the goal and to the drawing of conclusions.

In general, the situations represented by the other equipment, with regard to the margin between the error and the AC, shown in the I-MR charts, are similar to the situation represented by the comparison table. This suggests the possibility of increasing the frequency of verifications on these instruments, which, consequently, may bring several benefits to the company, including the reduction of costs associated with these processes.

Additionally, cases in which the graphs detect situations out of statistical control, or cases in which they detect a greater proximity between the error and the AC, reinforce the idea that these charts are useful for monitoring these instruments, besides helping to prevent certain equipment from being used without being fit for the intended use.

CONCLUSIONS

This article describes a method for checking the status of MMEs, based on the analysis of verification data using control charts – EWMA and I-MR charts. Usually, in each verification/calibration only one measurement is made. Therefore, these two types of charts are suitable since they can use sample size n=1. The analysis of these charts allow to ensure that between calibrations the equipment remains fit for its intended use.

For that, a case study was used, and the control charts were applied to nine MMEs that integrate the production process of an organisation. For the analysis, the results of instruments historical verifications were collected and analysed.

It was concluded that the joint analysis of the graphs provides important information about the MME status. Through this method it becomes possible to follow the evolution of the MME status and in case of presence of assignable causes and errors close to the maximum admissible error (outlined by the AC) to shorten the period between calibrations/verifications. In this sense, for situations out of statistical control, if the margin between the AC and the errors is significant, it is neither compulsory nor even necessary to restore normality, i.e., error stability. Otherwise, with little or no margin, it is necessary to restore normality, i.e., to try to reach a stable situation again and to control the MME more frequently. On the other hand, the method can also show that in certain cases the period between calibration/verification can be extended without putting at risk the compliance of the equipment with the requirements.

AKNOWLEDGEMENTS

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REFERENCES

Baldo, C. R., Probst, G. M. and Dewulf, W. (2020) ‘Process behavior charts used to check the consistency of CT instruments’, *Procedia CIRP*, 96, pp. 330–335. doi: 10.1016/j.procir.2021.01.096.

De Capua, C. *et al.* (2005) ‘A virtual instrument for estimation of optimal calibration intervals by a decision reliability approach’, *VECIMS 2005 - IEEE International Conference onVirtual Environments, Human-Computer Interfaces, and Measurement Systems*, 2005(July), pp. 16–20. doi: 10.1109/VECIMS.2005.1567553.

Claro, F. A. E., Costa, A. F. B. and Machado, M. A. G. (2007) ‘EWMA and $\bar{X}$ control charts for the monitoring of autocorrelated processes’, *Producao*, 17(3), pp. 536–546. doi: 10.1590/s0103-65132007000300010.

Fallah Nezhad, M. S. and Akhavan Niaki, S. T. (2010) ‘A new monitoring design for uni-variate statistical quality control charts’, *Information Sciences*, 180(6), pp. 1051–1059. doi: 10.1016/j.ins.2009.11.033.

Gaber, S. E. (2021) ‘Adjusting external calibration intervals for auxiliary devices in testing laboratories according to intermediate checks results’, *Water Science*, 35(1), pp. 82–88. doi: 10.1080/23570008.2021.1938435.

Morello, R. and Paciello, V. (2014) ‘A decisional model for estimating reliability curve and maintenance intervals of instrumentation’, *Instrumentation Science and Technology*, 42(4), pp. 446–457. doi: 10.1080/10739149.2013.878844.

Oliveira, E. C. de and Jesus, V. C. B. M. de (2015) ‘Management of calibration intervals for temperature and static pressure transmitters applied to the natural gas industry’, *Journal of Natural Gas Science and Engineering*, 24, pp. 178–184. doi: 10.1016/j.jngse.2015.03.019.

Portella, W. and Frota, M. N. (2006) ‘Frequency of Calibration: A critical issue for quality control in the pharmaceutical industry’, *18th IMEKO World Congress 2006: Metrology for a Sustainable Development*, 3, pp. 1897–1899.

Scouse, R. A. (1985) *Introduction To Statistical Quality Control.*, *Plastics and rubber international*. doi: 10.2307/2988304.

Stuart, M., Mullins, E. and Drew, E. (1996) ‘Statistical quality control and improvement’, *European Journal of Operational Research*, 88(2), pp. 203–214. doi: 10.1016/0377-2217(95)00069-0.

The integration of technologies Industry 4.0 technology and Lean Manufacturing: A systematic literature review

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STRUCTURED ABSTRACT

Purpose - Since the development of Lean Manufacturing (LM) in the last century, industry performance has improved. In 2011, when Germany first used the term Industry 4.0 to refer to the fourth industrial revolution, many changes in the way things are done have been discussed and applied. Industry 4.0 involves new technologies such as the Internet of Things (IoT). However, the LM originally does not consider the possibilities of these new information technologies and current research highlights the need for studies on the applications of industry 4.0 technologies in LM environments. Thus, this research aims to identify, select, evaluate, and synthesize the relevant evidence available on the literature around the integration of Industry 4.0 technologies and LM.

Design/methodology/approach - The research applied the method of systematic literature review on 107 articles, which were refined by this method.

Findings - The creation of value and increase in the company's profit occurs through I4.0 technologies, such as the Internet of Things, Cyber Physical System, use of the Cloud, quality (big) data, Robotics, among others, which provide real-time capability, decentralization, modularity, interoperability, service orientation, and virtualization. Visualizing thus, a support of the industry 4.0 concept to LM and vice versa, where the technologies related to this concept allow improving the flow of information exchanged, guaranteeing the interconnection of machines, things and people.

Research limitations/implication - Some important research may not have appeared in the search due to limitations of the systematic literature review method.

Practical implications - The findings point insights directions for future research and provide practitioners with insights into the integration of Industry 4.0 technologies and with LM.

Originality/value - The literature lacks articles that discuss the relationship of Industry 4.0 technologies with Lean Manufacturing.

Keywords: Lean Manufacturing, Industry 4.0, Lean 4.0

Paper type: Literature review

INTRODUCTION

Lean Manufacturing (LM) aims to improve the company's productivity through exercises to identify and eliminate processes that do not add or produce waste and expenses in an organization (Sony, 2018). According to Omoush (2020) Lean can be considered as one of the most significant contributions in the history of manufacturing management. However, from the beginning, its development is almost independent of information technology.

Kolberg and Zühlke (2015) also state that, as LM was invented in the last century, this principle does not take into account the possibilities of current information and communication technologies.

According to Sony (2018), the manufacturing industry underwent an innovation through the digitization of Industry 4.0 (I4.0) activities, which raised automation to a level well above what was known before. Introduced in Germany in 2011, changing the way of integrating the physical world with the cyber world in the organization, through artificial intelligence, cloud technology, internet of things (IOT), among other technologies. The I4.0 has been a trend in manufacturing since 2013, when it was officially unveiled in Germany, using automation technology. According to Dombrowski et al. (2017) I4.0 was developed with the aim of dealing with the challenges that grow in the 21st century.

By searching the Web Of Science (WOS) and SCOPUS, using the keywords “Industry 4.0”, “Lean Manufacturing” and “Impact”, the lack of studies on this topic, when associated, was observed. Rosin et al. (2019) brings in their study the need for more research to suggest new applications for Industry 4.0 technologies to further support Lean principles at the levels of control, optimization and autonomy. Pagliosa et al. (2019) reports some opportunities for future studies, two of which are the categorization of I4.0 and LM technologies at different levels of value stream and examine the effects of the relationship between them on operational performance. Finally, Tortorella and Fettermann (2017) concluded in their study that with the growth of Industry 4.0, the applicability of LM will be important, and its principles and practices are likely to become more relevant as the new industrial revolution makes it possible to understand better structure customer demands through easier data analysis. Therefore, given the possibility of seeing new synergies and opportunities to optimize engineering along the entire product value chain and based on the investigation carried out in this research, different perspectives of interaction will be presented that could be used to fill this gap, identified by the impacts of I4.0 on LM.

As both production paradigms continue to hold promise for solving future manufacturing challenges, the question is how they can relate to each other (Mayr et al., 2018).

Thus, considering the relevance of the theme, the research question is: How is the literature that relates Industry 4.0 with Lean Manufacturing?

The article contributes towards providing an overview of the theme of Industry 4.0 with Lean Manufacturing, which can be useful to guide future research on the subject. In addition, the study presents insights into the relationship between Industry 4.0 technologies and Lean Manufacturing tools, which can be useful for companies to direct their efforts.

RESEARCH METHODOLOGY

The method used was the systematic review of the literature, seeking to increase the transparency of research, increasing its replicability and decreasing the position and opinions of researchers in the results, and the review should be comprehensive and not biased in its preparation. According to Tranfield et al. (2003) the systematic review is based on three stages: planning, conduction and dissemination, which will be developed according to the planning defined in the question to be answered, the locations and databases to be searched, the search terms, the search expressions, the search period, the inclusion and exclusion criteria of the works to be considered, in the conduction, the quantitative data of the previous stage are presented, in addition to the evaluation, extraction and identification of the category of articles, finally, the dissemination stage consists of carrying out a descriptive analysis using the categories identified in the conduction phase, in addition to a thematic and interpretative analysis of the main contributions of the works.

In relation to the purposes, the research is exploratory, as it seeks to investigate the conditioning factors to achieve the objective of the study, in order to provide more accurate information about the impacts that Industry 4.0 can generate on the concept of Lean Manufacturing in the manufacturing environment and descriptive, in order to characterize the conditioning factors found.

RESULTS

Initially, the adaptation of the concepts to be searched was elaborated, thus generating a Table 1 with the appropriate search parameters for each base to be searched and containing the appropriate amounts of results generated. The chosen databases were Web of Science (WoS) and Scopus, the choice was based on the greater international scope of these platforms. To better detail the evolution of the literature on the association of the studied concepts, LM and I4.0, the search was not limited to a specific period.

Table 1 - Search parameters

Data base	Search parameter	Articles

Web of Science	TS=(Industry 4.0 AND Lean Manufacturing AND (Impact OR interaction))	44
Scopus	(TITLE-ABS-KEY (industry 4.0) AND TITLE-ABS-KEY (lean AND manufacturing) AND TITLE-ABS-KEY (interaction OR impact))	63

The first search resulted in a total of 107 articles, 44 articles found on the Web of Science and 63 studies in Scopus. This was the first article found in 2017. In the first screening, incomplete articles, or articles with languages other than English or Portuguese, were removed, resulting in 48 articles. Subsequently, after reading the title, abstract, methodology and conclusions, the exclusion criteria, defined in the planning stage, were applied and 13 were left to be analyzed. Figure 1 summarizes a little and in parts the whole process of filtering the studies.

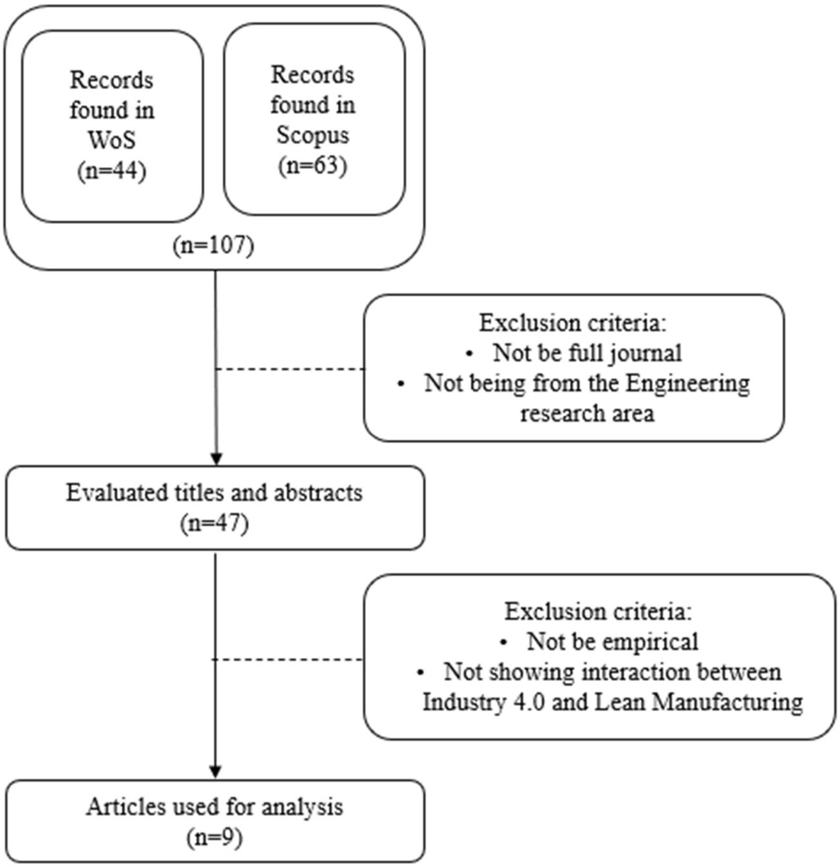


Figure 1- Article filtering procedure

The studies resulting from the analysis were submitted to a deep analytical reading, which sought to identify the possible impacts generated by the interaction of both concepts. From the review of the sample articles, aiming to characterize the literature on the instrument to answer the research question, it was possible to perceive a frequent analysis of how the technologies resulting from the fourth revolution can interfere, impact and collaborate with the processes and tools of the concept LM. It is clear the importance of continuing to use Lean in the manufacturing environment and using technologies as a basis for process improvement. In this way, some categories were also previously identified in the preliminary reading referring to the years of the article, journals and countries in which they were published, which will be shown in the following item.

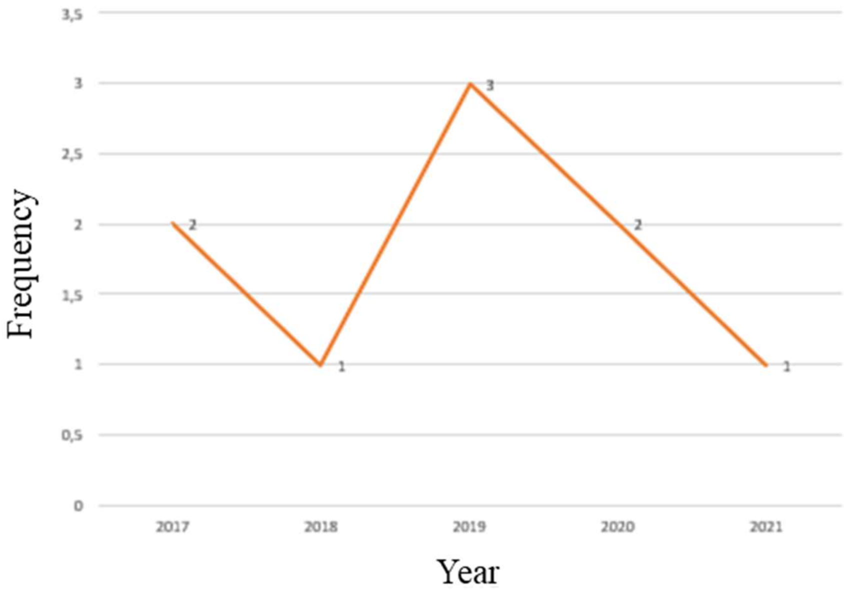
The nine selected articles are distributed in seven journals and their respective areas, according to Table 2. It is observed that the journal with the highest frequency is the International Journal of Production Research.

Table 2- Journals of the analyzed articles

Journal	Study Area	Frequency
International Journal of Production Research	Science, engineering, technology and medicine	3
Journal of Manufacturing Technology Management	Science, engineering, technology and medicine	1
International Federation for Information Processing	Computing engineering	1
FME Transactions	Mechanical engineering	1
International Journal of Automotive and Mechanical Engineering	Automotive engineering, mechanical engineering, multidisciplinary design optimization and energy conversion	1
IEOM Society International	Industrial Engineering (IE) and Operations Management (OM)	1
ICQEM Conference	Quality Management, Quality Engineering and Organizational Excellence	1

The evolution of publications can be seen in Chart 1 where it is noted that there is no trend, but the number of articles and years is relatively low to draw more conclusions about.

Chart 1 - Distribution of publications by year



Among the countries that were the object of study, the distribution of publications on the subject is shown in Table 3. Brazil concentrates 33% of the total publications, followed by Canada with 2 publications (22%) and the other countries: Germany, Japan, Portugal and Morocco with one publication each.

Table 3- Publications by country

Country	Frequency
Germany	1
Japan	1
Brazil	3
Canada	2
Portugal	1
Morocco	1

According to Sanders et al. (2017) LM tools and practices are influenced by organizational culture and vary between different business contexts, leading to the creation of different versions of lean models. This plethora of ML tools, techniques and methodologies is aimed at eliminating waste, however these tools go by various names and potentially overlap with each other and may also have different methods of implementation by various researchers.

Therefore, in order to provide a common and widely accepted source, some tools, these being the most reported in the study articles, were presented in Figure 2 and will be the basis for further analysis.

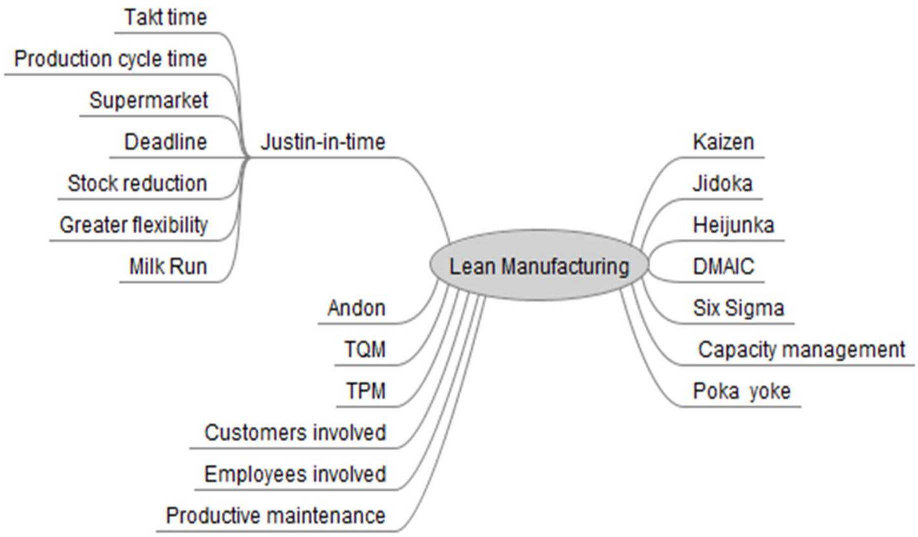


Figure 2- Mind Map Lean Manufacturing Processes and Tools

Ten technologies are identified in the articles studied as technologies used by Industry 4.0, which are used in this document as the principles of Industry 4.0 for further analysis (Figure 3).

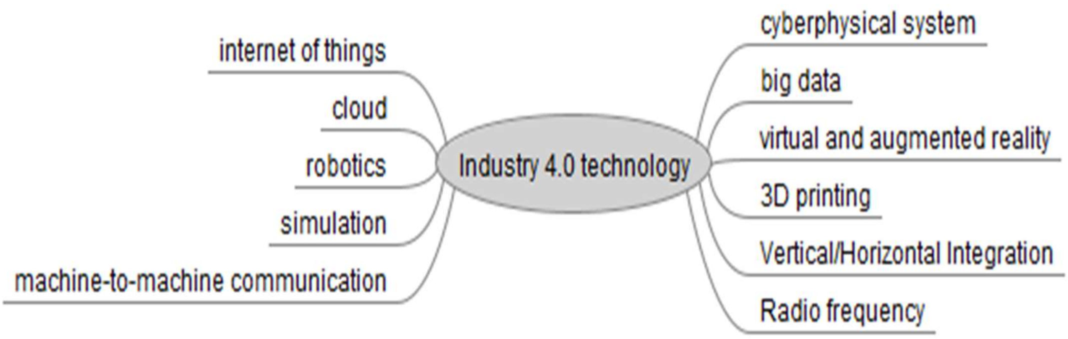


Figure 3- Mind Map Industry 4.0 Technologies

The link between I4.0 and LM is formulated in order to resolve the above issues and the prevailing skepticism about compatibility. The basic intention is to develop a relationship between the LM tools already presented and the technologies of Industry 4.0.

Since each article analyzed brings an approach and a way of relating the I4.0 with the LM, therefore, initially a table was created to present the technologies used by each article and which were addressed at a higher level, according to Table 4 to follow.

Table 4 - List of technologies addressed in each article studied

Technologies*	**T1**	**T2**	**T3**	**T4**	**T5**	**T6**	**T7**	**T8**	**T9**	**T10**	**T11**
Continuous Improvement Programs and Industry 4.0: Descriptive Bibliometric Analysis(Santos and Martins, 2020)	X	X	X	X	X		X				X
How Industry 4.0 Can Enhance Lean Practices (Pereira et al., 2019)	X	X	X	X	X	X	X	X			
Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries (Ghouat et al., 2021)	X	X	X	X	X	X	X	X		X	X
Impacts of Industry 4.0 technologies on Lean principle (Rosin et al., 2019)		X	X	X	X	X		X	X		
Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies (Tortorella and Fettermann, 2017)		X	X	X			X	X	X	X	
Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions (Pagliosa et al., 2019)	X	X	X	X	X	X		X	X		
The Relationship between Lean and Industry 4.0: Literature Review (Taghavi et al., 2020)	X	X	X	X	X			X	X	X	
Industry 4.0 and Lean Management – Synergy or Contradiction? (SANDERS et al., 2017)											
The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda (BUER et al., 2018)											
Percentage of articles that include technology in their study	71%	100%	100%	100%	86%	57%	57%	86%	57%	43%	29%
Notes:* T1: Cyber-physical System; T2: Internet of Things; T3: Big Data; T4: Cloud; T5:Virtual and augmented reality; T6: Robotics; T7: 3D printing; T8: Simulation; T9: Vertical/ Horizontal Integration; T10: Machine-to-machine communication; and T11: Radio frequency											

It is noticed that the Internet of Things, Big Data and the use of the Cloud are the most used technologies, being addressed in 100% of the seven analyzed articles, then we have Virtual and Augmented Reality and Simulation with 86%, the Cyber Physical System was cited in 71% of the articles, Robotics, 3D Printing and Vertical/Horizontal Integration were found in 57%, machine-to-machine communication in 43% and with lower rates Radiofrequency with only 29%.

Then, each study was analyzed individually, observing the relationships generated differently in each article. The study by Ghouat et al. (2021) entitled Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries, it is worth considering the Internet of Things and Machine-to-Machine Communication with a strong impact on real-time tracking of customer demand and Work in progress and finished product inventory, but on these same LM indicators, Big Data analysis did not generate any impact, as did robotics, with the latter technology having a small impact on the production cycle time.

Santos and Martins (2020) unfolds details on the links between continuous improvement programs and Industry 4.0 technologies applying bibliometric analysis methods in the article named Continuous Improvement Programs and Industry 4.0: Descriptive Bibliometric Analysis, reports that the most relevant authors combine lean manufacturing to RFID and IoT and six sigma to big data analytics and that most of the influential journals publish papers on computer sciences, industrial engineering, environmental sciences, and business, management, and accounting. Regarding the technologies, IoT, big data, and machine learning show a higher frequency of occurrence.

Taghavi et al. (2020) addresses Lean as the foundation for Industry 4.0 in the article The Relationship between Lean and Industry 4.0: Literature Review, exposing the interaction between I4.0 and LM and how I4.0 completes the LM, through the review of some studies and reporting the possible contributions of each article associated with the factors used and with that, the results of each case are reached, such as the increase in profit with the combination of concepts, the tools I4.0 can provide a solution to LM-related difficulties, such as inadequate management and poorly organized manufacturing systems, in addition to collaborating with data storage correctly, it reduces the time between failure notification and failure occurrence, makes systematic management of the supply chain more efficient and faster supplies, improves the supply chain through the Internet of Things, among others.

The article Impacts of Industry 4.0 technologies on Lean principles concludes that the categories of Lean principles that are most improved by Industry 4.0 technologies are Just-in-Time and Jidoka, while the least affected categories of Lean principle are Reduction of Waste and People and Team work. Regarding technologies, Internet of Things and augmented reality are mainly used to support the monitoring level, while, predictably, autonomous robots mainly support the autonomy level and Simulation is the most widely used technology at the optimization level (Rosin et al., 2019).

In a slightly different way, the article Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies cites the digital technologies researched in the Brazilian industrial context and also the LM practices and operations, and evaluates the improvement in operational performance observed during the last three years, from According to five indicators: productivity, delivery service level, inventory level, work safety (accidents) and quality (scrap and rework), the findings suggest that companies that are widely implementing LM practices are more likely to adopt Industry 4.0 technologies and their operational performance seem to be positively impacted by such an association, but it does not report exactly how each indicator is impacted (Tortorella and Fettermann, 2017).

The article How Industry 4.0 Can Enhance Lean Practices shows through a table which Lean tools are supported by which Industry 4.0 technology and reports that in general terms, every emerging technology can provide potential benefits in the existing reality, however, it is important to evaluate carefully how effective this technology is in each real case and context (Pereira et al., 2019).

And the article Industry 4.0 and Lean Manufacturing: A systematic literature review and future research directions shows the technologies and cites application examples, such as: , the Internet of Things can help Lean with Inventory control and material traceability, data sharing with the network to optimize preventive maintenance, provides real-time information to support management decision making, etc., the Cyber Physical System, corrects failures through interconnected systems, employs self-optimizing manufacturing systems aiming at zero defects, ensuring process security, etc., the use of the Cloud, integrating and sharing with different sectors of the plant, performs remote maintenance management of complex equipment, reduces the space for data storage, stores and shares data between different companies (data warehouse), shares company's data and information with the internal and external public, establishes communication between ERP systems of different companies, the use of Big Data to manage data to optimize the maintenance of complex equipment, reduces the time to make decisions based on history, helps in the creation of new products based on customer relationship management (CRM) and their preferences, in addition to performing market analysis and monitoring different degrees of customer satisfaction, in relation to horizontal/vertical integration, it helps to integrate different sectors of the company such as engineering and production, integrates information technology systems horizontally and vertically to obtain productivity, cost and quality gains, share data within the entire value stream, use Robotics to collaborate with the testing and inspection of finished products, perform high-precision assemblies (e.g., assembling microdevices on microchips), perform tasks in collaboration with humans (collaborative robots), Augmented Reality helps in solving workstation problems through the use of devices such as tablets, smart glasses or smartphones, supports carrying out maintenance remotely through knowledge sharing and technical guidance, and simulation, facilitates the construction of prototypes and samples, it also to simulate projects and processes in different production and programming scenarios (Pagliosa et al., 2019). This last article is the one with the most detail on the interaction of concepts and application of I4.0 technologies in LM processes.

And the last two papers analyzed the technologies different from other papers already mentioned. The article Industry 4.0 and Lean Management – Synergy or Contradiction? presents an interdependence matrix between the principles of LM and Industry 4.0, in order to demonstrate to what extent the design principles of I4.0 are supporting the LM tools, the analysis is done by representing a coefficient of support. As principles of I4.0 present, real-time capability, decentralization, modularity, interoperability, service orientation and virtualization. Already from the principles of LM there are Kaisen, TPM, 5S, TQM, Kanban, Takt Time, Heijunka, Andon, Poka Yoke among others. The matrix shows that most interactions of the LM tool with Industry design principles 4.0 receive a supporting effect or at least a neutral effect. The only exception is takt time which encounters a hindrance effect, the article concludes that, the concept of takt time will be eliminated in the smart factories of the future, due to the fact that takt time calculation is done centrally with the help of demand forecast and product variants. Therefore, rush orders cannot be easily integrated into production with fixed takt times that are completely contradictory to the Industry 4.0 objective of decentralization and autonomy, among other reasons. On the other hand, TPM had the maximum benefit of Industry 4.0 design principles, this was due to the fact that machine and plant conditions can be monitored in real time (e.g. energy consumption, machine breakdowns, output quality, OEE), through intelligent algorithms, failure patterns can be predicted in advance and the personnel involved can be notified which in turn makes maintenance planning, forecasting, spare parts logistics more easy and effective. It also reports on some of the basic elements for implementing I4.0, since some of the interactions of the LM tool (such as modularity vs. standardization, decentralization vs. SMED) may have scored less in terms of efficient benefit, but these LM tools, in turn, assist in the successful implementation and operation of Industry 4.0. Value stream data is fed into the cloud and machines continuously access it via the Internet of Things. The current status of the value stream is monitored and if there is any discrepancy, it reacts independently to solve the problem without central control (Sanders et al., 2017).

And finally, the article named The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda aims to establish a framework for summarizing the literature, using four ways of relating the concepts, being (a) Industry 4.0 technologies can support and further develop well-known lean manufacturing practices, i.e. The Industry 4.0 supports lean manufacturing; (b) The established lean manufacturing systems exert facilitating effects on Industry 4.0 implementations, ie, lean manufacturing supports Industry 4.0; (c) The changes imposed on the production system by the integration of Industry 4.0 and lean manufacturing affect different dimensions of system performance, that is, it illustrates the performance implications of an Industry 4.0 and lean manufacturing integration and (d) Based on similar studies, it is likely that environmental factors influence the potential to integrate Industry 4.0 and lean manufacturing, as well as the performance resulting from such an integration, i.e., it portrays the effect of environmental factors on an integration of Industry 4.0 and lean manufacturing. (Buer et al., 2018).

CONCLUSIONS

The question of the study is answered, visualizing the positive impacts of Industry 4.0 on LM processes through the use of technologies that come along with the digitization of the fourth revolution. In addition, it was possible to observe that the LM can serve as a basis for I4.0, resulting in a relationship between the concepts and a complement of the I4.0 to the LM.

LM considers any activity that does not add value to the product as waste and takes them out of the manufacturing process to reduce costs, while I4.0 optimizes the computerization of the third industrial revolution and makes the manufacturing process smarter, more efficient and more productive, and the applicability of LM will acquire a special importance with the introduction of Industry 4.0, taking companies to higher levels of excellence. Thus, the identification of a positive association between the implementation of both approaches provides managers and professionals with arguments to improve their business processes and sharpen their organizational culture according to LM principles and practices, while introducing Cyber Physical System technologies and Information Technology in a collaborative way.

In other words, the concept of industry 4.0 supports the principle of lean manufacturing where technologies related to this concept allow improving the flow of information exchanged, ensuring the interconnection of machines, things and people. Most authors confirm that the integration of LM and I4.0 has positive impacts on companies. However, it is worth noting that Industry 4.0 alone does not cover all Lean principles and does not replace them with the management approach that represents it.

The article has limitations found referring to the small number of articles that deal with the integration of Industry 4.0 to LM, since the concept of Industry 4.0 is still not so well consolidated and needs to be further researched, as it is still a recent topic. The article also investigates only empirical works, which further reduces the number of articles found and thus makes it difficult to reach a real conclusion on the subject.

Another limitation due to the sample size of articles found and analyzed in the text is a lack of achievements in the USA and China, which, as described by Santos and Martins (2020), are the countries with the most scientific production in the area of lean and Industry 4.0 studies and that cause the greatest impact of studies found, as well as the low number in Japan and Japan. Therefore, another sample must be created in order to enrich the article with a redefinition of filters, considering the example of non-empirical work and other areas of study besides engineering, allowing the study of more articles.

Therefore, more research should be carried out to suggest new applications for Industry 4.0 technologies to further support Lean principles at the levels of control, optimization and autonomy. Furthermore, it would be relevant to test, in factory or manufacturing contexts, the extent to which Industrial 4.0 technologies improve the implementation of LM principles and, ultimately, the productivity of manufacturing companies. A relevant research perspective would be to validate the impact of Industry 4.0 technologies on industrial systems and to support Lean principles.

Therefore, the interactions provided in the research between Lean management and Industry 4.0 serve as a basis for future research regarding the implementation of I4.0 technologies in industries, considering the Lean philosophy to obtain the future smart factory.

REFERENCES

Buer, S. et al. (2018) 'The link between Industry 4.0 and lean manufacturing : mapping current research and establishing a research agenda', International Journal of Production Research, 7543, pp. 1–17. doi:10.1080/00207543.2018.1442945.

Dombrowski, U.; Richter, T.; Krenkel, P. (2017) 'Interdependencies of Industrie 4.0 & Lean Production Systems: A use case analysis.', Procedia Manufacturing, 11, pp. 288–1295.

Ghouat, M., Haddout, A. and Benhadou, M. (2021) 'Impact of Industry 4.0 Concept on the Levers of Lean Manufacturing Approach in Manufacturing Industries', International Journal of Automotive and Mechanical Engineering, 18(1), pp. 8523–8530.

Kolberg, D. et al. (2015) Lean Automation enabled by Industry Lean Automation Automation enabled enabled by Industry' IFAC-PapersOnLine, 48(3), pp. 1870-1875.. doi:10.1016/j.ifacol.2015.06.359.

Mayr, A. et al. (2018) 'Lean 4.0 – a conceptual conjunction of lean management and Industry 4.0.', Procedia CIRP, 72, pp. 622–628.

Omoush, M.M. (2020) 'Management Science Letters', 10, pp. 3107–3118. doi:10.5267/j.msl.2020.5.012.

Pagliosa, M.,Tortorella, Guilherme and Ferreira, J.F. (2019) 'Industry 4.0 and Lean Manufacturing A systematic literature review and future research directions', Journal of Manufacturing Technology Management, 32(3), pp. 543–569. doi:10.1108/JMTM-12-2018-0446.

Pereira, A.C. et al. (2019) 'How Industry 4.0 Can Enhance Lean Practices', FME Transactions, 47(4), pp. 810-822.. doi:10.5937/fmet1904810P.

Rosin, F. et al. (2019) 'Impacts of Industry 4.0 technologies on Lean principles', International Journal of Production Research, 58(6), pp. 1644-1661. doi:10.1080/00207543.2019.1672902.

Sanders, A. et al. (2017) 'Industry 4.0 and Lean Management – Synergy or Contradiction ?', In: IFIP international conference on advances in production management systems. Springer, Cham, pp. 341–349. doi:10.1007/978-3-319-66926-7.

Santos, P.H. and Martins, R.A. (2020) 'Continuous Improvement Programs and Industry 4 . 0 : Descriptive Bibliometric Analysis', (September).

Sony, M. (2018) 'Industry 4.0 and lean management: a proposed integration model and research propositions', Production & Manufacturing Research, 6(1), pp. 416–432. doi:10.1080/21693277.2018.1540949.

Taghavi, V. and Beauregard, Y. (2020) ‘The Relationship between Lean and Industry 4 .0: Literature Review’, In Proceedings of the 5th North American Conference on Industrial Engineering and Operations Management, Detroit, MI, USA (pp. 808-820).

Tortorella, G.L. and Fettermann, D. (2017) ‘Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies’, International Journal of Production Research, 7543(October), pp. 1–13. doi:10.1080/00207543.2017.1391420.

Tranfield, D., Denyer, D. and Smart, P. (2003) ‘Towards a methodology for developing evidence-informed management knowledge by means of systematic review. British journal of management, 14(3), pp. 207-222.

Downtime Reduction in a Small Company Using DMAIC Methodology

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ABSTRACT

Purpose - This work aims to present a detailed process of reducing downtime in a small company of animal food manufacturing in Brazil.

Methodology - The authors used the DMAIC (Define, Measure, Analyze, Improve, Control) methodology in a real situation.

Findings - There was a reduction in the occurrence of interruptions for a given stopping reason, which represented a decrease in idle time of 44%. There was also a suggestion for another downtime issue.

Originality/value - Optimizing equipment availability and reducing production downtime helps industries remain competitive since the generation of losses in the production process becomes a limiting factor for increasing production efficiency. This work shows how it is possible to obtain improvements with few resources and contributes to shedding more light on the particularities of implementing DMAIC initiatives in SMEs.

Keywords: Lean Six Sigma (LSS), DMAIC, Small and medium-sized enterprise (SME), animal nutrition.

Paper type: Case study

INTRODUCTION

Companies in the industrial sector are very concerned with increasing productivity as they seek to remain competitive. One way to achieve this result is by optimizing the availability of equipment and reducing production downtime since the losses generated in the process become a limiting factor for increasing production efficiency (Ananth and Vinayagam, 2015).

In the agro-industrial sector, it is no different. According to Carvalho et al. (2016), animal feed and mineral supplements have gained space in the Brazilian market. This sector has a high impact on the economic growth of agribusiness and the productive performance of livestock (Fucillini and Veiga, 2015). Despite the high demand for mineral supplementation, the area is inserted in an environment of high competitiveness among the companies participating in this market (Augusto et al., 2016).

Quality Management aims at good performance in the market and improves the efficiency of processes, minimizing waste and expenses with non-quality in production operations (Carpinetti, 2017). At the end of the 1980s, the most recent Quality Management program called Six Sigma emerged, presenting statistical thinking with an emphasis on quality control and analysis to create solutions (Montgomery and Woodall, 2008).

According to De Mast and Lokkerbol (2012), an internationally known method for directing Six Sigma projects is DMAIC. In addition to statistical thinking, it provides strategic guidance on quality, unfolded in relevant projects. There is still a substantial impact on the cost-benefit ratio of these projects, in which some companies achieve significant economic results (Schroeder et al., 2008).

Furthermore, in the systematic review by Costa et al. (2018), a low scientific production was identified on Six Sigma applications in the animal feed industry, which justifies the accomplishment of this work. From the point of view of the productive context, Brazilian cattle ranching has about 220 million head of cattle. The region studied is fifth in the production ranking, with a percentage of 8.7% of the total number of animals (IBGE, 2020), exporting meat all over the world.

The present work aims to present proposals to minimize the production downtime of a company in the animal nutrition sector by applying the DMAIC methodology.

RESEARCH METODOLOGHY

The research is described as exploratory and explanatory since it seeks to find the factors that contribute to the occurrence of a result. From the perspective of approaching the problem, it is quantitative and qualitative since it investigates the cause-effect relationship of a phenomenon and uses statistical techniques.

Characterization of the company

The company studied is an animal nutrition factory located in Mato Grosso do Sul, Brazil. The industrial unit employs 60 employees distributed between the production and administrative sectors. The commercial sector provides a team of trained technicians formed by zootechnicians, veterinarians and agronomists focused on generating results through guidance related to the management of supplementation and the correct indication of products.

The organization's portfolio is intended for beef cattle, sheep and horses. It features about 37 products categorized into: mineral, mineral with urea, protein mineral, protein energy, feed and nucleus. More than 80% of the line is geared towards raising cattle, given the state's market potential.

The factory environment has five mixers (machines). Unlike industrial agitators that work with liquids, mixers have the function of homogenizing solid materials. This characteristic is apparent in the quality of the mixing result. Machines 1 and 2 are responsible for producing the premix, considered the most important component of the recipe because it guarantees the main nutrients in the composition of the final product. The other equipment is designated for the manufacture of the finished product. Machines 3 and 4 are responsible for producing the mineral, mineral with urea, nucleus and mineral protein line. While Mixer 5 produces the entire feed line, energetic proteins and nucleus.

The production process takes place in batches, i.e., the operations that make up the process are repeated throughout production. Each batch is called a "beat" by the employees of the company studied, since the main step is a mixture. The total weight of the beat may vary according to the equipment's capacity and the number of bags requested by the customer. Consequently, the number of bags is also modified, i.e., if the total weight is reduced from 1000 to 500 kilos and each bag weighs 25 kilos, the result will drop from 40 to 20 bags per beat.

DMAIC

Uluskan (2016) states that DMAIC is a methodology that helps apply the Six Sigma structure and proposes the improvement of existing processes. The Six Sigma program is based on statistical tools and the analysis of variability, which gave it the name "Six Sigma", that is, six standard deviations. It promotes strategic alignment by establishing performance goals adjusted to the organization's results as targets for improvement projects (Tjahjono et al., 2010).

In this way, the DMAIC proposes improving the process through the correct indication of projects and steps to solve problems organized cyclically and constantly, collaborating for continuous improvement (Montgomery and Woodall, 2008). Carpinetti (2017) describes its phases as follows:

Stage 1 - Definition: phase of precise determination about the project to be addressed, in which the objective and problem to be addressed will be defined. The final decision on the project definition must consider the possible benefits concerning the reduction of waste and non-quality costs and raising the necessary resources and people involved.

Step 2 - Measurement: data collection phase that collaborates in the investigation of the characteristics of the problem. It provides information for the analysis of the causes of the problem.

Stage 3 - Analysis: phase of identifying the main causes of the problem. The fundamental objective of this step is to verify the relationship between the undesirable effect and its causes. At the end of the analysis, the aim is to obtain an explanation for the problem and an indication of proposals for improvement.

Stage 4 - Improvement: planning and execution phase of the actions found in the previous stage. This step may still require experiments to validate the improvement suggestions.

Step 5 - Control: phase to ensure that the good results are preserved and not lost.

Data collection and analysis

The data used for the work refer to Machines 2, 3, 4 and 5. Mixer 1 generated a minimum amount of downtime, so the machine was disregarded from the data set. The workday is 9h/day, with a 15-minute grace period to start production and a 5-minute break during the afternoon shift. Data collection was carried out during the working days of 2018: operators were instructed to fill in a production form at each stop and late start.

In the “start field”, the time when production started was recorded. If this time exceeded the 15-minute tolerance, the operator should justify the reason that caused the delay. The “pause field” is filled out with the start time of a stop during production and the “restart field” with the time when production was resumed, resulting in the duration of the stop. This field is justified with the reason in a similar way to the delay.

The data recorded in the manufacturing environment were entered into a virtual spreadsheet that presents the production date, the mixer, the product manufactured, and the duration of delays and stops, duly justified according to the physical record. From this, qualitative and quantitative tools were used for data analysis.

RESULTS

Define

The macro production process in Figure 1 describes both the finished product and pre-mix machines. Both are initiated in the weighing of raw material. All ingredients entering the mixer must be weighed according to the recipe plates provided by the company's technical department. After this phase, they are placed in the machine and transported to the mixing equipment, which remains in operation for a certain time for each machine.

With the elements appropriately homogenized, the product is packed and sent to the storage location, where it remains until the moment of its expedition. The pre-mix differs in that it is sent to the mixers. The finished product is sent to the final customer.

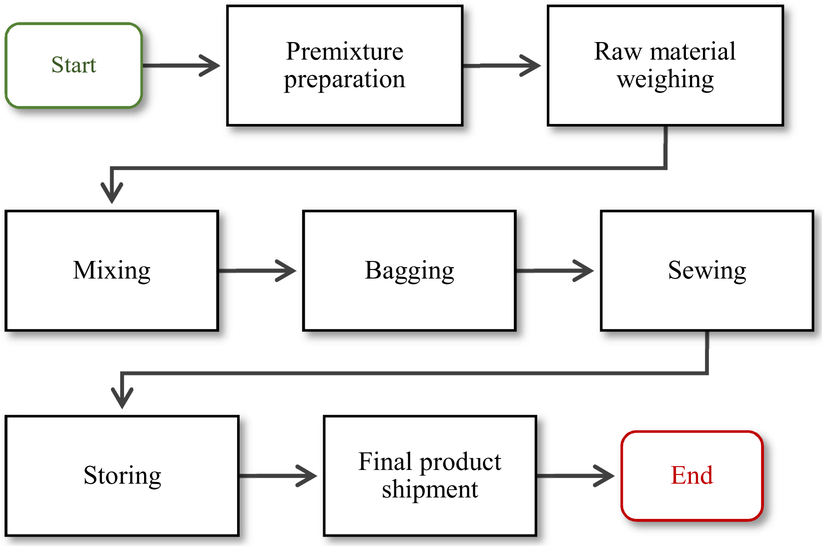

Figure 1 – Production macro-process

The company classifies minerals into micro and macro according to the quantity purchased. The macro-ingredients used in greater quantities during the year are carbonate, phosphate, salt, urea, silicate and sulfur. On the other hand, the micro-ingredients stock has a greater variety of raw materials, such as zinc sulfate, sodium bicarbonate, yeast, milk aroma, and choline chloride.

Inside the factory, a sector is responsible for weighing all the micro-ingredients for the finished product machines. This sector weighs all the raw material that enters the mixer for the premix, even those considered macro. Two weighers receive a production order with the pre-mixes and the number of beats that will be manufactured the following day. Then, they get a set of plates from the technical department to advance the weighing of at least one beat for the next day's production.

The weighing process is monitored by an employee responsible for placing each ingredient already weighed on the scale again to verify that the weight is following the recipe plate. Next, the machine team transports the weighed ingredients to the mixer to fill the equipment. The operator responsible for this step follows a loading sequence described on the plate provided by the technical department.

This sector also determines the mixing time, essential for the next step, initiated by activating the mixer and the timer.

The weighing of macro ingredients is performed manually on conventional scales. Machines 3 (M3) and 4 (M4) have fixed weighers, while Machine 5 (M5) has a different operator each day, according to a rotation predetermined by the leader. The M5 (Figure 2) features semi-automatic cereal weighing. The leader follows a weighing sequence according to the recipe plate and, through the control panel, activates buttons to carry out the weighing on a silo scale. On the other hand, the other machines require the removal of the cereal in bags and manual weighing on traditional scales and its transport in carts to the mixing equipment.

The M5 employee pours the already weighed ingredients into the hopper one at a time to supply the mineral. With the elevator on, they are transported to the silo scale already filled with the recipe cereal. After checking the total beat weight on display, the machine leader can unload these products into the mixer. In the other machines, the cereals are supplied manually through the hopper and the mineral since the set of equipment does not have the silo scale or the transport connected to the buffer silo.

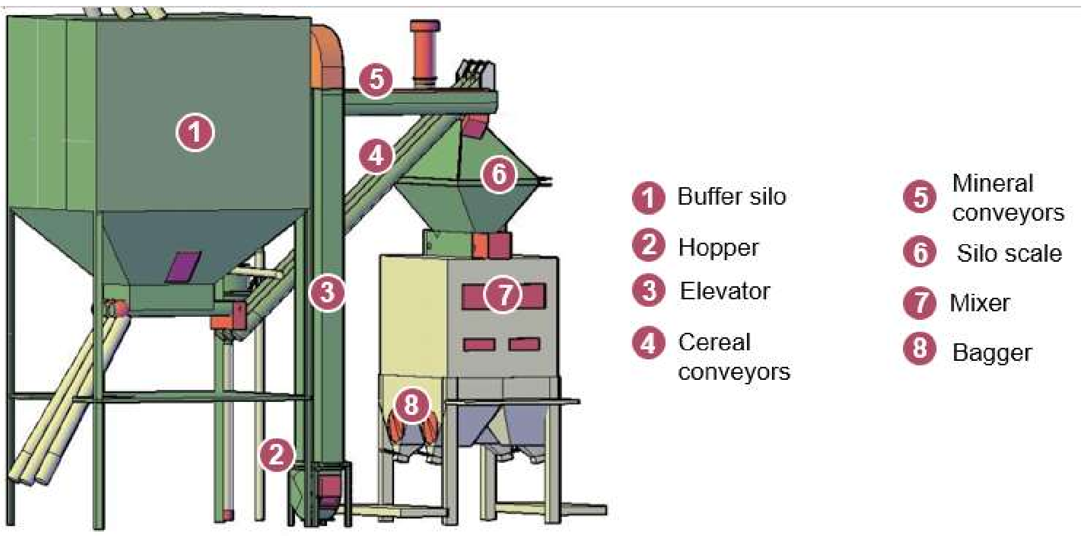

Figure 2 – Mixer 5

Bagging begins after mixing. The bagging operator takes the product through the end of the bagging machine and places it on top of a scale. The same operator that supplies is responsible for removing or putting the product in the bag until it reaches the exact weight, sewing and placing it on the platform cart to take it to the storage location. Each bag comes stamped with the batch defined by the date of manufacture and the beat number. The bag slides down a tube to the warehouse, where it will wait for its shipment to be carried out by the loading/unloading team. To better understand the process, Figure 3 shows the flow of raw materials from entry to the final destination.

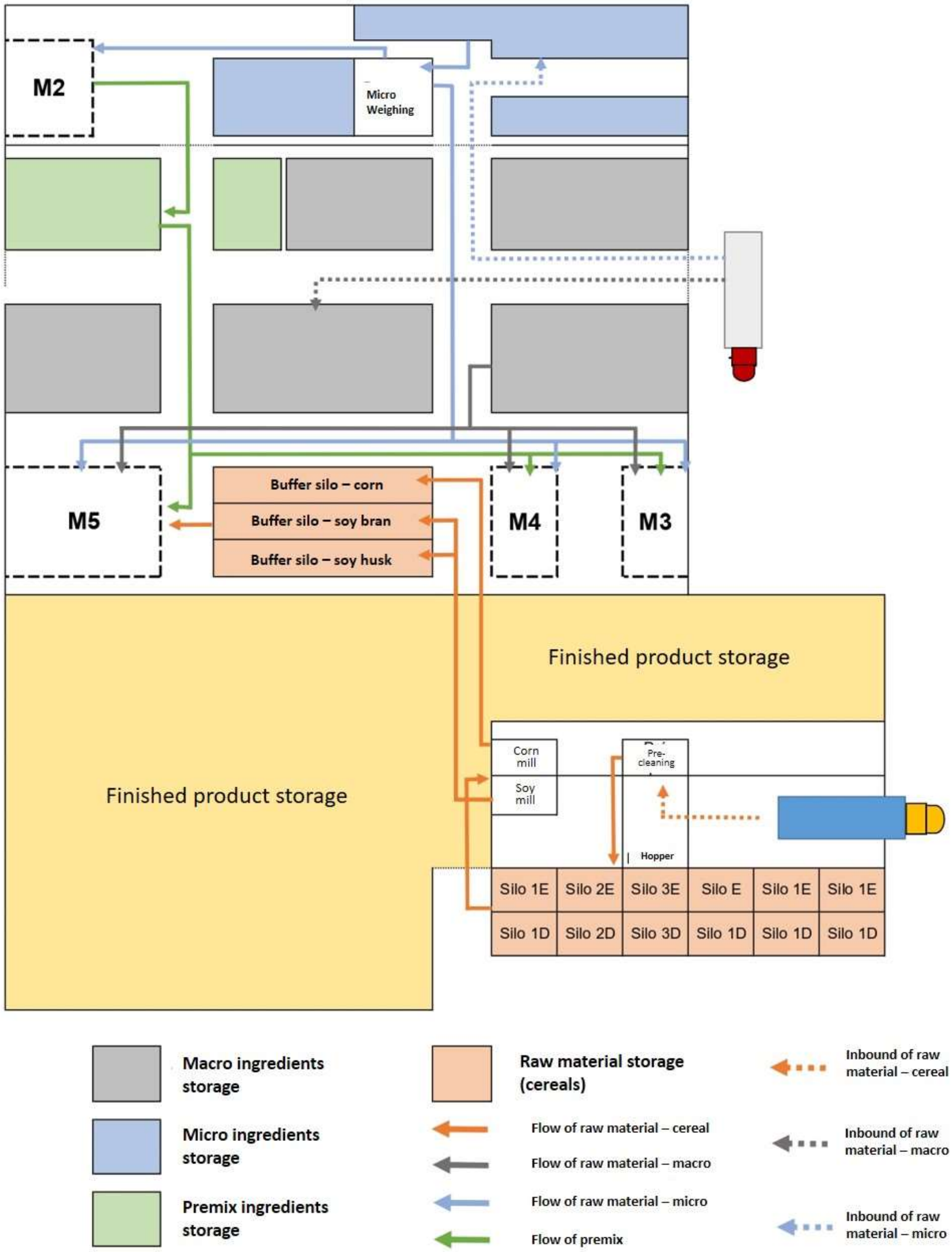

Figure 3 – Flow of raw materials

In this phase of the DMAIC, an attempt is made to delimit the problem by processing the information in Excel software. The data collected on Machines 2, 3, 4 and 5 during 2018 totaled 549.6 hours of downtime, equivalent to 61 working days and 1197 occurrences of delays and stops during production. Figure 4 shows the performance of these two variables during the months of the year.

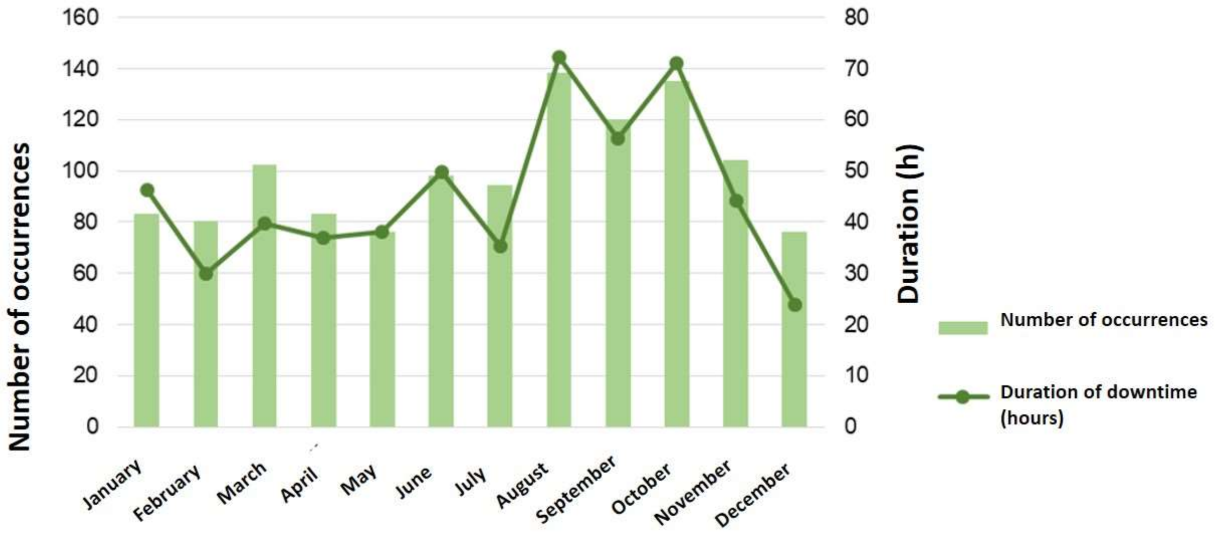

Figure 4 – Total duration of downtime

August registered the highest idle time of 72.1 hours and 138 occurrences, equivalent to 14% of the total downtime for the year. On the other hand, December was the month with the shortest duration of downtime, with around 23.8 hours and 76 occurrences, which suggests some delays and short-duration stops. However, it cannot be considered a positive result since they worked for 11 days in that month due to the collective vacation at the end of the year.

Measure

The measurement phase was elaborated from observations on the shop floor and brainstorming with those involved in the process. The process mapping was carried out by machine due to the objective and characteristics of each piece of equipment being different. Finished products that use a higher concentration of corn, bran and husk inputs are manufactured in Machine 5, as it has automated weighing through the silo scale. The steps that directly involve the machines are repeated with each beat. That is, weighing the ingredients, filling the machine, mixing and bagging.

The reasons for pauses and delays were divided into scheduled and unscheduled ones. The scheduled ones are subject to programming and predetermined duration by the leadership. The unscheduled ones occur unexpectedly. Unscheduled delays before production starts represent 80% of available data. There were 319 occurrences and duration of almost 129 hours during the year 2018. In comparison, the scheduled ones present 81 occurrences (70 hours and 41 minutes).

Unscheduled stops during production account for 61% of available data. A total of 483 occurrences and duration of 307 hours during the year 2018. At the same time, the scheduled ones present 307 occurrences (44 hours and 56 minutes). Most of the scheduled stops were of short duration but in large numbers. When stratifying the data by machine (Figure 5), the highest unscheduled downtime is Machine 5, with 195 hours and 31 minutes. Then Machine 4 (almost 42 hours), Machine 2 (28 hours) and Machine 3 (20 and a half hours).

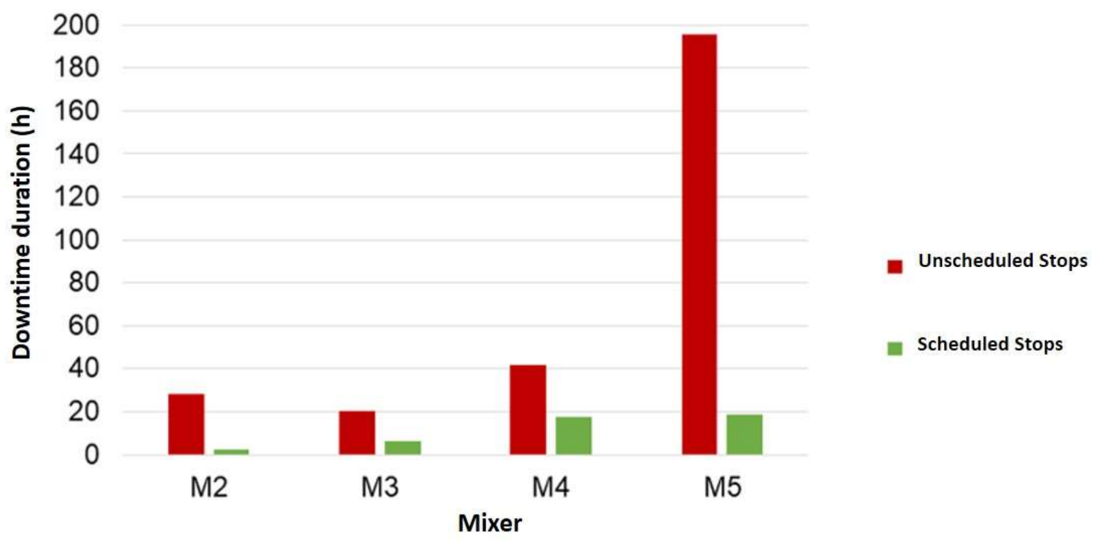

Figure 5 – Duration of stops per machine

The Ishikawa diagram is used to represent the relationship between the "effect" (problem) and the possibilities of "cause" that contribute to the occurrence of this effect. This tool is similar to a fishbone, in which the central axis shows a basic flow of information and the spines that converge to it configure secondary interferences to the analyzed problem. Usually, for problems of an operational nature, it is recommended to choose the following groups that classify the causes: man, machine, method, material, measurement and Mother Nature (environment). Figure 6 displays the Ishikawa of downtime and delay reasons. Red arrows indicate unscheduled causes, while green arrows point to scheduled causes.

A Pareto chart is a statistical tool also known as the 80 by 20 principle or ABC analysis. It demonstrates that, for many phenomena, 80% of the consequences result from 20% of the causes. In this way, companies can plan and direct their resources toward relevant issues. Figure 7 was developed to investigate the most impacting unscheduled downtime justifications in the dataset. The reasons "weighing monitoring", "not justified," and "plates" were grouped as "Others" and resulted in 1 hour and 32 minutes. "Corrective maintenance", "Full Tube" and "Lack of corn" account for more than 50% of downtime. Together they total 145 hours and 37 minutes.

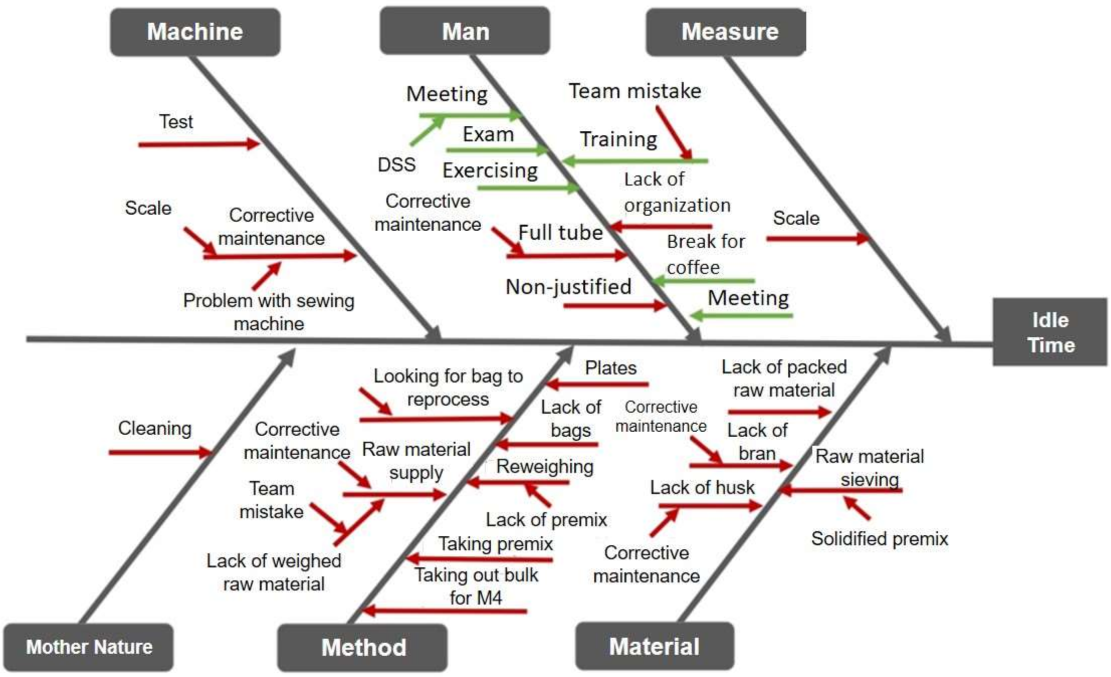

Figure 6 – Cause and effect diagram of machine downtime

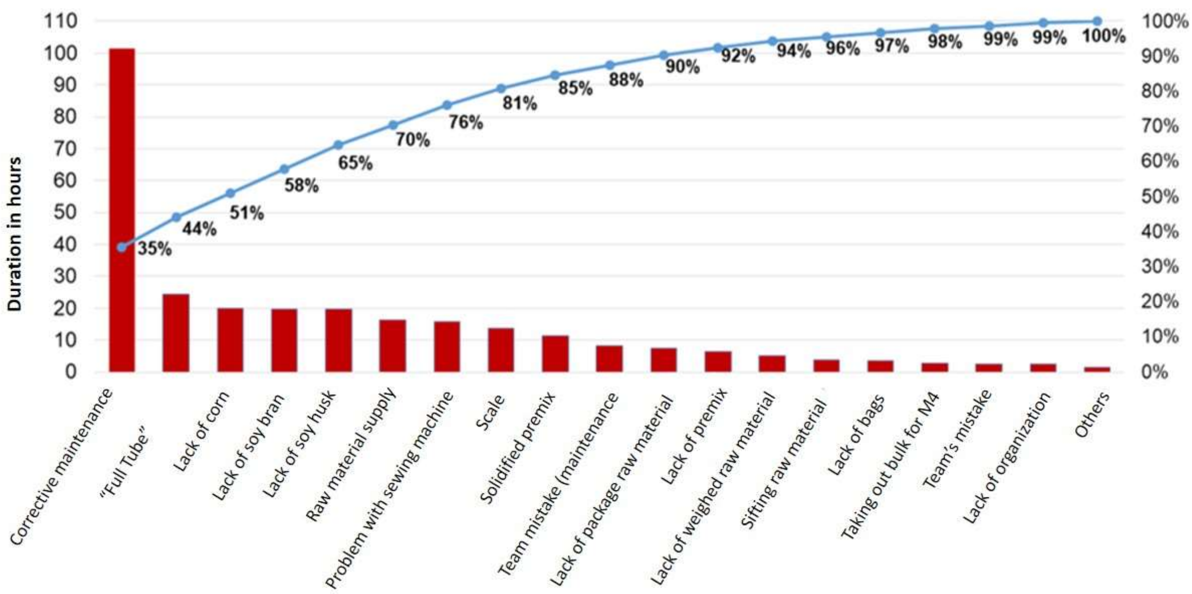

Figure 7 – Pareto chart of unscheduled downtime justifications

Given the conclusion presented above, it was decided to investigate the causes of Corrective Maintenance and “Full Tube” through the interrelationship diagram. The “Full Tube” problem occurs when the flow of bags of finished product from the production area to the storage area is interrupted, causing the accumulation of bags in the tube.

The interrelationship diagram is a graphical representation that helps identify the relevant items in a complex problem, considering the logical relationship between cause and effect through arrows. In this way, it allows directing the possible solution to the difficulty being studied more properly, pointing out the root cause and the effects of the problem. This tool can be used as a complement to the Ishikawa diagram. Before developing the diagram, unstructured Brainstorming was applied to those directly involved.

To develop the “Full Tube” interrelationship diagram, which is the focus of this work, observations were carried out in loco to identify the possible causes of the problem. Subsequently, an informal interview was held with the warehouse leader and some experienced industry employees to validate the causes already observed and find new reasons for this stop. With the information collected, the interrelationship diagram was created (Figure 8).

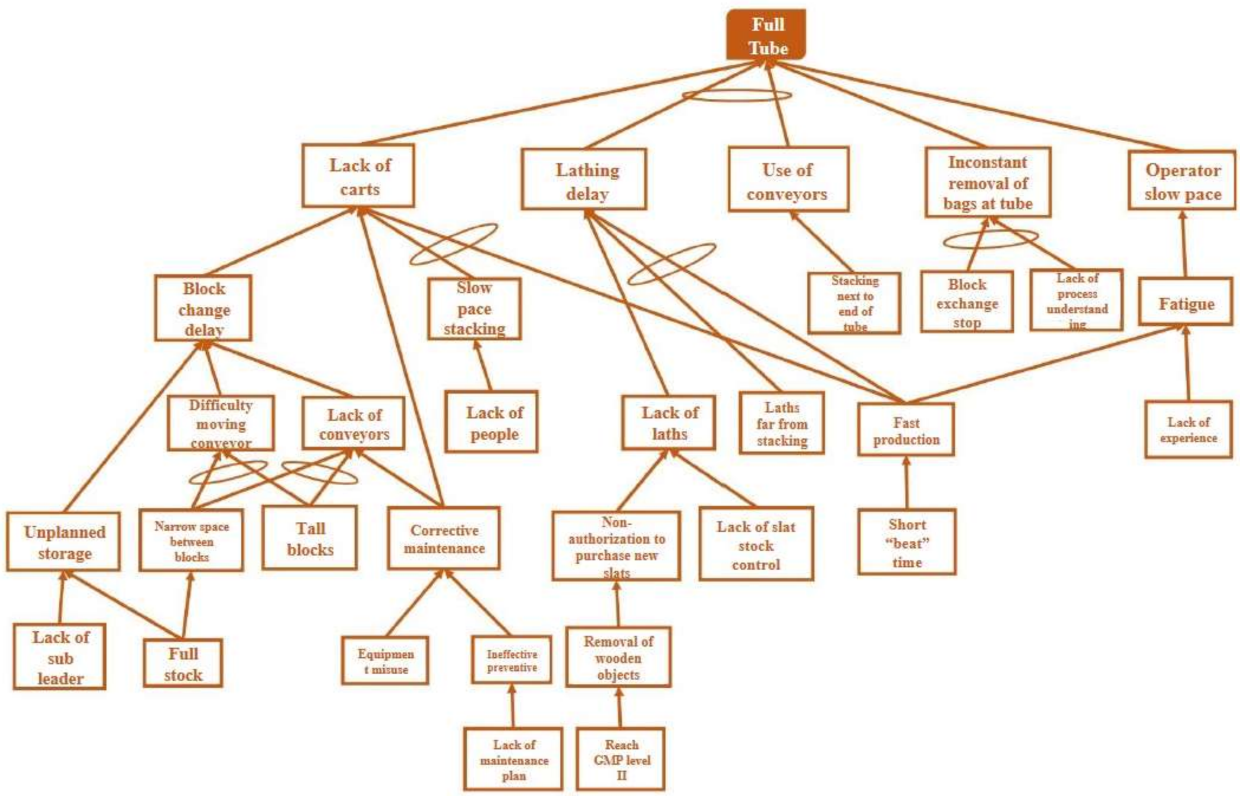

Figure 8 – Interrelationship Diagram for “Full Tube”

After analyzing the “Full Tube” interrelationship diagram, it is concluded that the leading causes of this problem are: lathing delay, fast production, corrective maintenance and delay in block exchange.

The interrelationship diagram shows that fast production is a common cause of lack of carts, lathing delay, and the slow pace of the operator at the end of the tube. In this case, the lack of carts means that all available carts for the end of the tube are occupied. The fast production associated with the slow pace can generate this problem, as shown in Figure 9.

Figure 9 – "Full Tube" occurrence

Lathing consists of interlocking the storage block using laths. Three interlocks are required per block (three stops for lathing). This process is quick: four laths are placed in a square on top of the block to continue stacking bags. However, it is necessary to get these laths from where they are stored. The distance traveled plus the fast production results in the lathing delay.

The lathing delay coupled with the use of conveyor belts results in a "Full Tube" situation. Storage locations close to the end of the tube make it possible to use conveyor belts instead of carts. Thus, the bags taken from the tube are placed directly on the conveyor belts. When there is a stop to lath the block, the bags automatically stop being removed from the tube. If this process takes too long, products accumulate in the tube immediately.

"Fast production" can also be influenced by the operator's slow pace. The step of removing the bags from the tube is performed manually by the accountable employee. During fast production, the bagger does not stop and the beats are superimposed, contributing to a constant production rhythm. In this way, the operator remains in constant movement, which results in physical fatigue and reduces his work pace over time.

Block storage change occurs when the stacked bag limit is reached. This limit may vary according to the product. For example, a mineral block can store up to 600 bags, while a feed block only holds 350 bags. During this step, the conveyor must be manually moved to where the product will continue to be stored.

Both the difficulty of moving the conveyor and the lack of conveyor can be caused by an association between tall blocks and narrow space between the blocks. Large conveyors become impracticable for the narrow aisles associated with tall blocks since their position in relation to the block makes manual stacking impossible. This fact generates the lack of equipment when the smaller conveyors are being used.

The next storage location is an influencing factor in the block change. Without this information, the team must decide at the time of the change, which delays this process. The warehouse leader is the one who decides the storage location, and in his absence, the team becomes responsible for the decision. In addition, when stock is full, planning is unfeasible, as storage occurs as the bags are shipped.

Corrective maintenance contributes to both lack of carts and lack of conveyors. Each station within the warehouse has some available carts. Each end of the tube has three carts and the others are destined for the expedition. If one of them is undergoing corrective maintenance, it may result in insufficient carts for bag picking. As the number of available conveyors is smaller than carts, the probability of their unplanned maintenance impacting the process is greater.

Analyze

The process mapping shows how the process operates, seeking to identify:

- the steps that add and do not add value
- the main outputs of each step
- main inputs and main requirements of the outputs
- bottlenecks and waste
- opportunities for optimizing steps

Despite the detailed process mapping done in the measurement section, it was decided to develop the process map related to the “Full Tube” problem and corrective maintenance. It helps to visualize the parameters considered noise and controllable, as well as assist in the creation of the FMEA (which is not shown in this work due to lack of available space). The “Full Tube” is directly linked to the storage process. Therefore, the steps described in the map were the storage phases. Figure 10 shows the map of this process.

In the first step of this map, the “beat” time is considered noise because it varies according to the product and cannot be controlled. In addition, the shorter the beating time, the better the efficiency of the production process, so this time tends to decrease. Block storage change can also be considered uncontrollable, as it occurs according to the quantity produced, which is impacted by seasonality and demand.

In the later stage, the corridor blocked is considered noise since the corridors are narrow and can be blocked by the conveyor or by the loading and unloading team to remove bags from the block. Space availability is defined as noise during block assembly, as it depends on shipping and sales, making it challenging to propose improvements or control this process variable.

In the block storage change, all parameters were considered uncontrollable. The problem of moving conveyors is influenced by the narrow aisles of the warehouse that are already predetermined. When the inventory is full, and consequently there are blocks with the maximum height allowed, this issue becomes more evident. However, full inventory is related to low demand, a factor that is also difficult to influence.

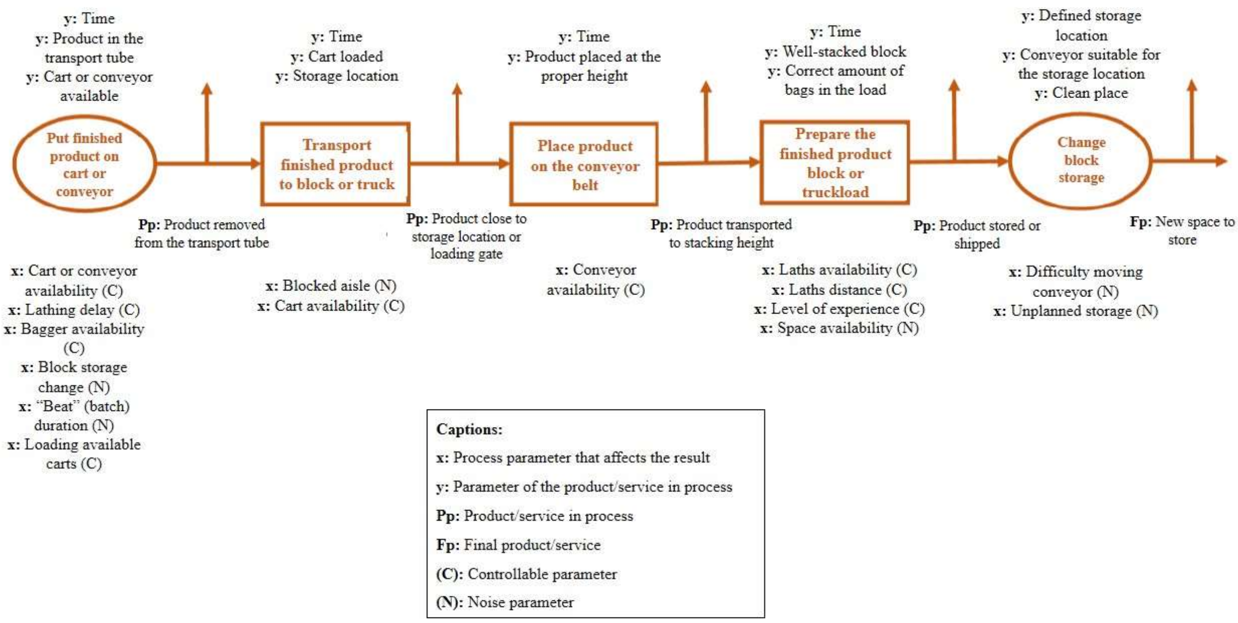

Figure 10 – Process mapping related to the "Full Tube" problem

Improve

In this section, the effort impact matrix and the 5W2H are presented. The first tool was used to filter the actions generated in the FMEA, and the second was used to describe the prioritized actions. An effort impact matrix is a suitable tool for decision-making on which actions will be chosen to achieve a goal within a certain period, optimizing limited time and resources by visualizing activities that should be prioritized and activities that should be postponed.

The FMEA results were analyzed given the number of variables relevant to the “Full Tube” problem. The “noise classification” of the variables was used as a parameter to indicate the effort level for collection, implementation or analysis of the issues. That is, all factors that were identified as noise were assumed as high effort, as shown in Figure 11.

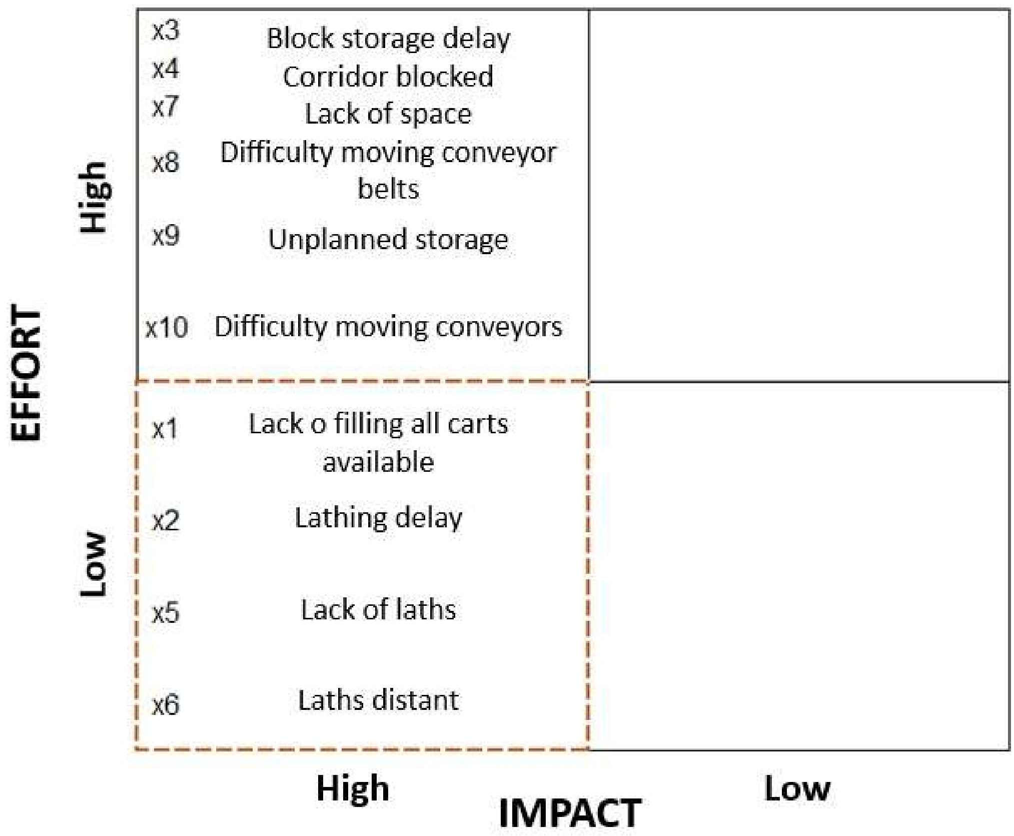

Figure 11 – Effort impact matrix for “Full Tube” issue

A 5W2H was developed for improvement proposals. This tool portrays the conditions of the activities that will be performed to achieve a particular objective within the following items: what will be done, when will it be done, who will do it, where it will be done, why it will be done, how it will be done and how much it will cost.

The proposed solution for the lathing delay, prioritized in the effort impact matrix, was disregarded since the “lack of laths” and “laths far from the block” directly influence this problem, so the suggestions for improvement for the two variables will have an impact on it. Therefore, the suggested actions (Figure 12) for “Full Tube” were:

- Awareness of the team about the need to use carts to reduce the “Full Tube” issue, minimizing the downtime of the bagger in cases of stoppages in the warehouse
- Proposal of new storage points for laths, in order to reduce the time spent moving to search for these tools
- Creation of the lath stock register in order to eliminate the problem of lack of laths.

What	Why	Who	How	How much	Where	When
Staff awareness of the need to use carts to minimize "Full Tube"	Minimize or avoid production downtime due to breaks in the storage process	Process Leader	Meet with the warehouse leader and his team to highlight the impact of the "Full Tube" issue and the importance of using all carts during delay occurrences in the warehousing process.	Man-hour cost	Warehouse	March 22nd
Proposal for new lath storage points	Reduce movement and avoid lathing delay due to laths away from the storage location	Process Leader	Creation of a current and future Spaghetti Diagram with the new storage points.	Man-hour cost	Power Point	-
Develop and implement lath inventory record	Control the lath inventory to avoid the lack of material causing the storage process to stop	Process Leader and Logistics Manager	Creation of a record to control the lath inventory and definition of minimum level inventory for the purchase of new laths.	Man-hour cost	Excel	-

Figure 12 – 5W2H for "Full Tube" improvement proposals

The problem of frequent breaks in removing bags from the transport tube was identified by on-site observations and informal conversations with employees. Most interruptions occurred due to the lack of use of the three available carts during the breaks in the stages after removing the bags.

Employees at the end of the tube filled only one cart during the normal flow of production, as well as during the interrupted flow. According to them, if they continued to fill the other carts, the later stage would be overloaded, and the flow would not return to normal. The attitude of these employees contributed to the occurrence of "Full Tube" situations. A meeting was held with the team to minimize this problem. It addressed the following topics:

1) The dependence of the process stages: It was necessary to address the interdependence between the stages of the production and storage process in order to show that the interruption of a process can cause inconvenience to the other;

2) Impact of the interruption of the bag removal from the end of the tube: The "Full Tube" data was presented, and the impact on production efficiency caused by production stops was highlighted;

3) Importance of using all available carts: It was identified that the time to place the bags on the conveyor is shorter than the time to remove the bags from the end of the tube; therefore, it is possible to regulate the flow of the storage process after filling the three carts.

One month after the meeting, another conversation was held with the team to congratulate them for reducing the occurrence of "Full Tubes" and encourage them to continue performing the procedure agreed in the previous meeting. The results of this suggestion are discussed in the control section.

Regarding new storage points for laths, the spaghetti diagram was used to illustrate the current and future lath transport. A spaghetti diagram comprises tracing the path taken by the material or people within an established layout to evidence and quantify unnecessary movements visually.

In Figure 13, 12 blocks were randomly chosen to exemplify the distance traveled to the current storage shelf. Figure 14 divides the warehouse into three zones: the green blocks would use laths from shelf 1, the blue ones from shelf 2, and shelf 3 would store laths for the orange blocks. The 12 blocks were used as an example in Figure 14, where the displacement reduction and flow improvement in the warehouse can be noted.

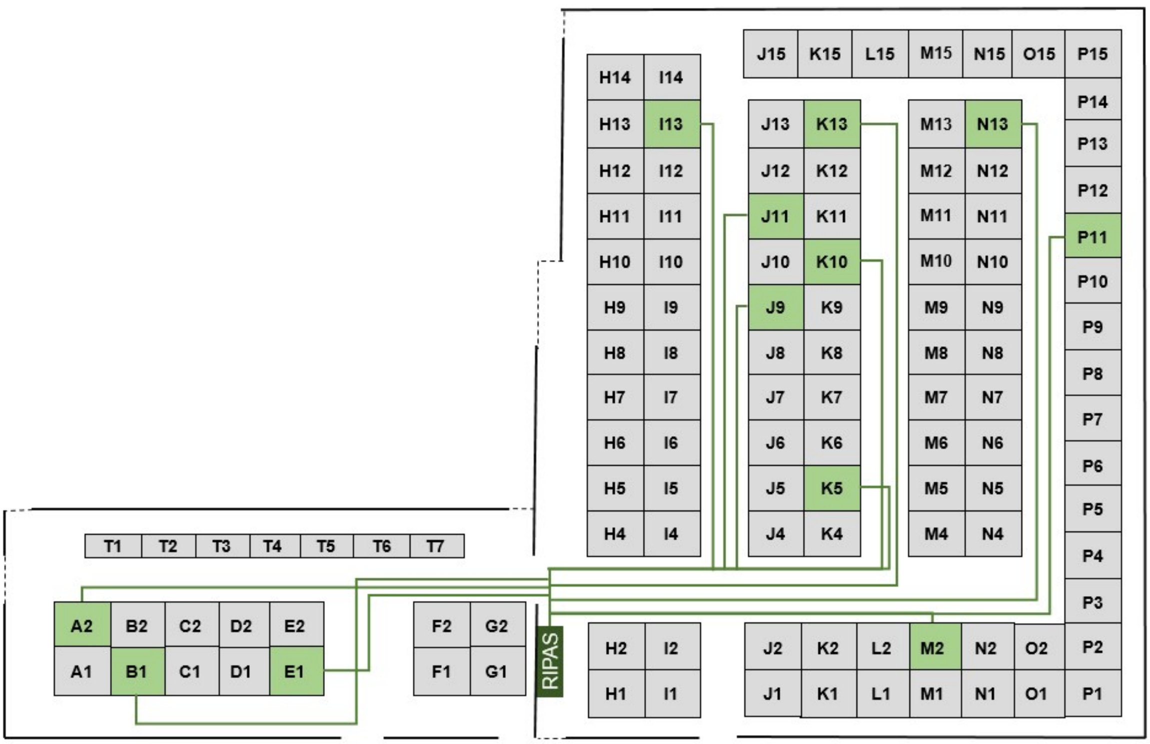

Figure 13 – Spaghetti Diagram for current situation

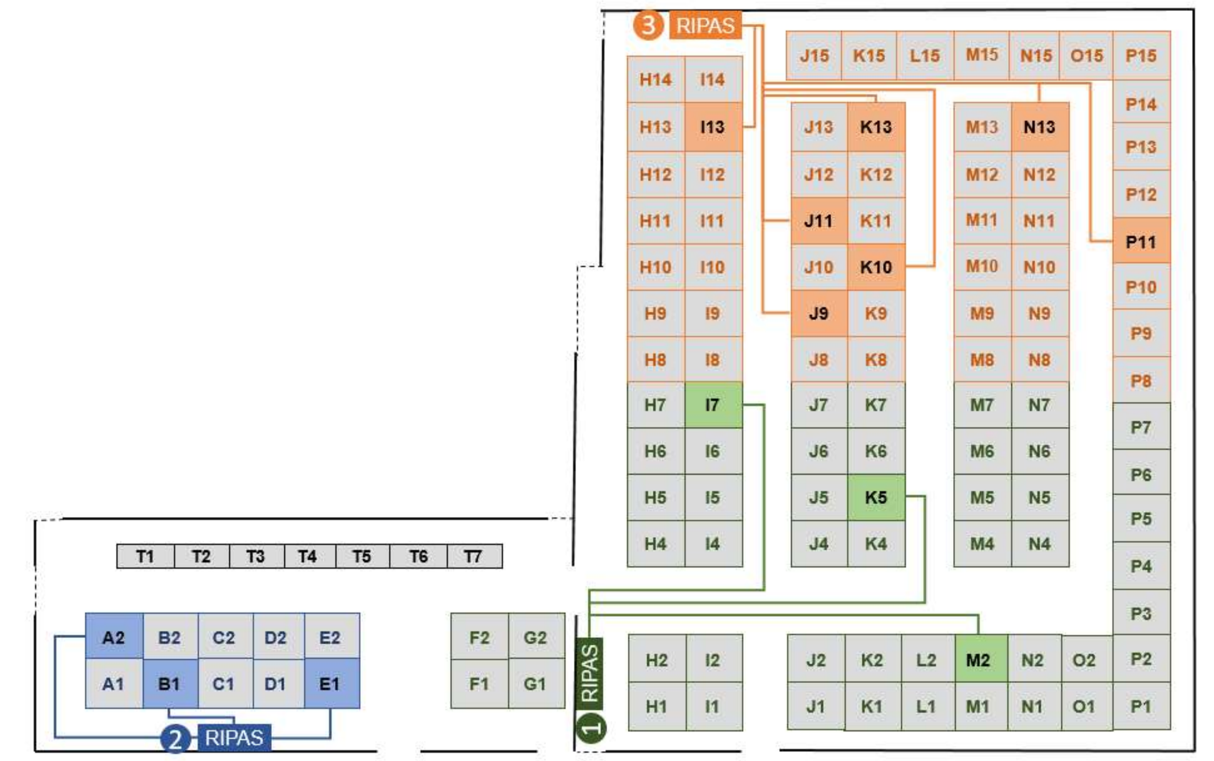

Figure 14 – Spaghetti Diagram with new storage points

Control

This section aims to demonstrate the results of the "Full Tube" problem through the first solution proposal (staff awareness of the need to use carts to minimize the "Full Tube"). Since it was implemented in March 2019, the "Full Tube" data from January 2018 to March 2019 were compared with the results obtained from April to September 2019.

The Anderson-Darling normality test was performed with a confidence level of 95% for the "Full Tube" data in both periods. As the results of the second period were non-normal, the Mann-Whitney test was used to investigate whether the occurrences of "Full Tube" reduced after March 2019. The hypotheses of the Mann-Whitney test were:

H_0: The medians of the two samples are the same.

H_1: The median of "Full Tube" occurrences before April 2019 is greater than the median of the second sample.

The p-value result was 0.0246 (Figure 15), less than 0.05; therefore, the null hypothesis is rejected. The alternative hypothesis is that the "Full Tube" occurrences were higher before the team became aware of the use of the carts.

```
Tubo cheio antes   17  13,000
Tubo cheio depois   6   3,500


Point estimate for η1 - η2 is 8,000
95,4 Percent CI for η1 - η2 is (-0,000;13,999)
W = 232,5
Test of η1 = η2 vs η1 > η2 is significant at 0,0250
The test is significant at 0,0246 (adjusted for ties)
```

Figure 15 – Mann-Whitney test result comparing “Full Tube” occurrences before and after improvement

As the interrelationship diagram showed that the inventory level influences the occurrences of “Full Tube”, it was decided to investigate the correlation between these two variables in order to ensure that the inventory level did not influence the result presented above. The data collected from the inventory refers to the number of bags available in the warehouse each day that there were stops due to a “Full Tube” problem. Figure 16 shows the correlation graph between inventory level and “Full Tube” occurrences.

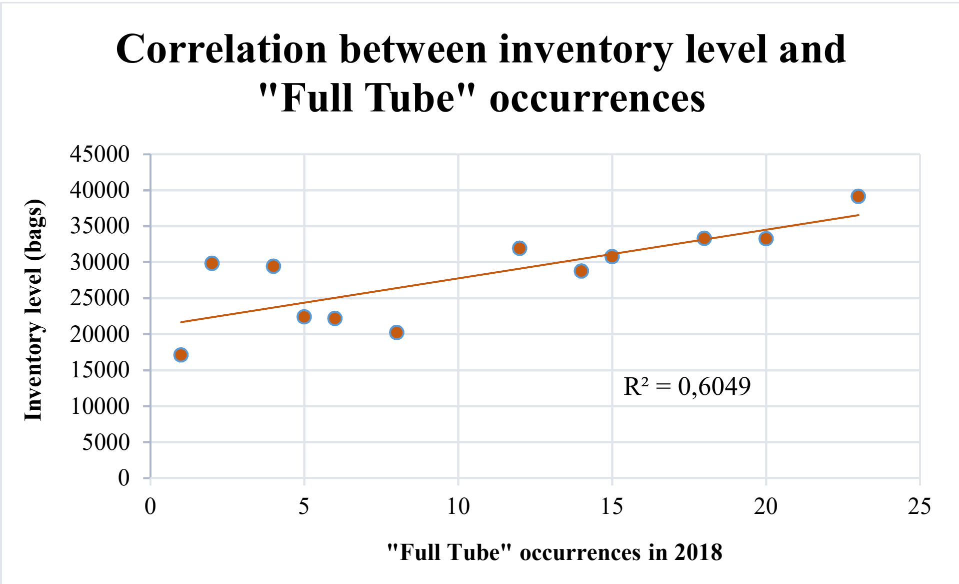

Figure 16 – Correlation Chart for 2018 inventory and “Full Tube” data

The result obtained was a coefficient of 0.78, which is classified as a strong correlation (Mukaka, 2012). However, it was necessary to ensure through statistical tests that the inventory level for the months before April 2019 was similar to the months after. A Mann-Whitney test was performed to investigate the hypothesis that the data sets are equal. A result of $p = 0.7136$ was obtained, that is, greater than the significance level of 0.05. The null hypothesis of equality between the samples cannot be rejected. The Boxplot tool was used to visually represent the reduction in the median of “Full Tube” occurrences after implementing the improvement, shown in Figure 17.

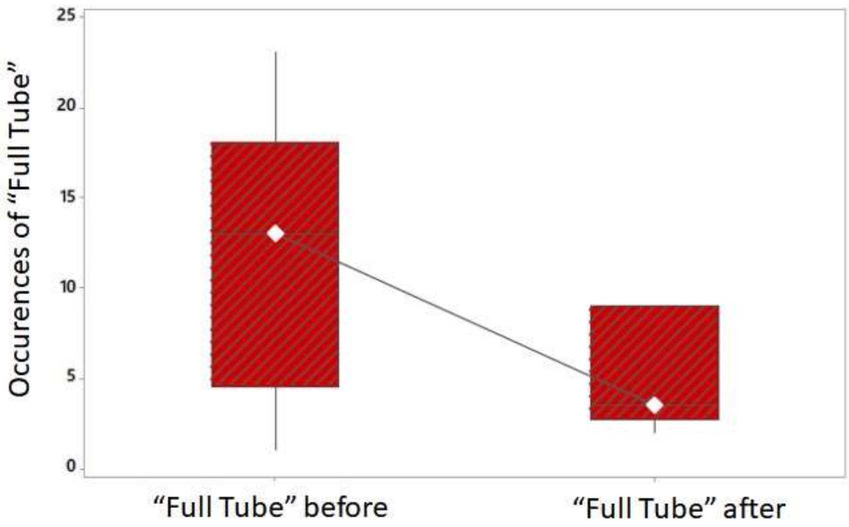

Figure 17 – Comparative boxplot for "Full Tube" occurrences before and after the improvement

It is concluded that there was an effective reduction in the occurrence of full tubes, that is, without the influence of the inventory level on the result.

CONCLUSIONS

The work developed aimed to present proposals to minimize the production downtime of a company in the animal nutrition sector through the application of DMAIC. The use of qualitative and quantitative tools in the methodology contributed to understanding the activities, tasks, and validation of the notions observed in loco. In addition, they allowed the identification of the causes of the most recurrent reasons for stoppages: "Full Tube" and corrective maintenance.

Three actions were suggested and implemented for the "Full Tube" problem. The first one has already shown concrete results: the team's awareness concerning the need to use carts for minimizing "Full Tube" occurrences, which was implemented in March 2019, resulted in a reduction in the frequency of the problem. There was a reduction of 4 hours and 38 minutes, comparing the period from April to September 2018 with the same period in 2019. It represents a 44% reduction in downtime within this period.

Another suggestion for improvement was the proposal of new storage points for laths. The spaghetti diagram allowed visualizing the situation before and after the implementation of the new storage points and the reduction of warehouse movement. Interferences in the storage process are expected to be reduced, allowing for a more continuous flow so as not to generate "Full Tube" events. In addition, it is possible to develop and implement a lath inventory record to avoid downtime due to the lack of this essential instrument for block staking.

Together with the maintenance team, it was possible to identify a relevant cause for the occurrences of emergency corrective maintenance. The lack of a maintenance plan led to the last improvement suggestion: creating a maintenance plan. The small database of detailed maintenance occurrences was presented as a limitation. Currently, the company is undergoing a process of improving maintenance information collection records, which will collaborate to generate data that will contribute to developing a future plan.

The main limitation of the research is that its results are based on a single case study. Therefore, there are restrictions in the generalization of the results. On the other hand, the tools applied in this work can be used as examples in many processes. The analysis of problems according to the Six Sigma methodology proved to be adequate for creating succinct and objective solutions, which allowed the minimization of the downtime of a production process and its consequent increase in efficiency as initially proposed.

DMAIC, like any method, is used without mobilizing the organizational culture, which has an isolated and immediate effect if not incorporated into the day-to-day of organizations. The company studied does not yet have a culture focused on continuous improvement. However, this action with positive results can be an excellent stimulus for managers to identify other opportunities to use DMAIC and start creating a culture of continuous improvement.

The contributions of this study can help in the decision-making of professionals involved with the management of several companies, but mainly those linked to the shop floor. More specifically, as a detailed example of the implementation of the DMAIC methodology in a small company, this case study contributes to the important task of shedding more light on the application of Six Sigma in animal food manufacturing companies and SMEs, given the existing gaps (Alexander, 2019). SMEs are essential for generating employment and income worldwide, so studies on increasing efficiency and improving processes in them should continue to be done.

REFERENCES

Alexander, P. et al. (2019), “Lean Six Sigma for small-and medium-sized manufacturing enterprises: a systematic review”, International Journal of Quality & Reliability Management, Vol. 36, No. 3, pp. 378-397.

Ananth, G. and Vinayagam, B.K. (2015), “Effectiveness improvement through total productive maintenance using particle swarm optimisation model for small and micro manufacturing enterprises", International Journal of Productivity and Quality Management, Vol. 16, No. 4, pp. 473-503.

Augusto, D.B. et al. (2016), "Planejamento agregado na indústria de nutrição animal sob incertezas", Production, Vol. 26, No. 1, pp. 12-27.

Carpinetti, L.C.R. (2017), Gestão da qualidade: conceitos e técnicas, Atlas, São Paulo.

Carvalho, A.L. et al. (2019), "Análise de modos e efeitos de falhas: abordagem extensionista aplicada a uma pequena empresa", Conecte-se! Revista Interdisciplinar de Extensão, Vol. 3, No. 5, pp. 86-100.

Costa, L.B.M., Godinho Filho, M., Fredendall, L.D. and Paredes, F.J.G. (2018), "Lean, six sigma and lean six sigma in the food industry: A systematic literature review", Trends in Food Science & Technology, Vol. 82, pp.122-133.

De Mast, J. and Lokkerbol, J. (2012), "An analysis of the Six Sigma DMAIC method from the perspective of problem solving", International Journal of Production Economics, Vol. 139, No. 2, pp.604-614.

Fucillini, D.G. and Veiga, C.H.A. (2015), "Controle da capacidade produtiva de uma fábrica de rações e concentrados: um estudo de caso", Revista Custos e Agronegócio, Vol. 10, No. 4, pp. 221-240.

Montgomery, D.C. and Woodall, W.H. (2008), "An Overview of Six Sigma", International Statistical Review, Vol. 76, No. 3, pp. 329-346.

IBGE (2020), "Pesquisa da Pecuária Municipal" available at: https://www.ibge.gov.br/estatisticas/economicas/agricultura-e-pecuaria/9107-producao-da-pecuaria-municipal.html?=&t=destaques (accessed 06 April 2022).

Mukaka, M.M. (2012), "Statistics Corner: A guide to appropriate use of Correlation coefficient in medical research", Malawi Medical Journal, Vol. 24, No. 3, pp. 69-71.

Schroeder, R.G. et al. (2008), "Six Sigma: Definition and underlying theory", Journal of Operations Management, Vol. 26, No.4, pp.536-554.

Tjahjono, B. et al. (2010), "Six Sigma: a literature review", International Journal of Lean Six Sigma, Vol. 1, No. 3, pp. 216-233.

Uluskan, M. (2016), "A comprehensive insight into the Six Sigma DMAIC toolbox", International Journal of Lean Six Sigma, Vol. 7, No. 4, pp. 406-429.

Diagnosing organizational culture of innovation: development and application of a systematized instrument

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ABSTRACT

Purpose - The aim of this paper is to develop a systematized instrument for diagnosing an organizational culture of innovation.

Design/methodology/approach - The following steps were carried out: identify elements related to the culture of innovation and current diagnostic models in the literature review; select the most relevant elements; systematize the elements into a unified instrument; and apply the systemized instrument in a pilot case.

Findings - Proposition of a Systematized Instrument for diagnosing an organizational culture of innovation with 6 dimensions of analysis and 38 questions.

Research limitations/implications - This study applied a pilot test with a limited sample to evaluate the proposed instrument. Therefore, future studies should focus on the application in a larger sample of organizations, in order to obtain statistical validation.

Practical implications - The application of the instrument in a pilot case brought visibility to the limiting factors of the innovation culture, whether in the company as a whole or in specific hierarchical levels and departments. Identifying the different perceptions of the dimensions and elements of an innovation culture can contribute to a personalized and aligned approach to cultural change. In addition, it allowed the company to recognize its strengths and limiting points within the innovation theme.

Originality/value - Systematization of concepts from other instruments, related to the culture of innovation and proposition of a diagnostic mechanism for organizations to increase the chance of success in implementing their innovation strategies. This systematization contributes to the evolution of instruments in the area.

Keywords: Innovation culture, Organizational culture, Innovation diagnosis, Systematized Instrument.

Paper type: Research paper

INTRODUCTION

Innovation has been perceived as one of the main forms of adaptation that companies use to survive and compete within the current market (Scherer and Carlomagno, 2016). Although necessary, innovation suffers from cultural barriers to happen within organizations (Benchmarking Innovation Impact, 2019). Culture of innovation is the set of guidelines, actions and decisions with the intention of innovating. Achieving the culture of innovation enhances innovation both in results and in continuity (Hogan and Coote, 2014). Organizations are not clear about the position they occupy in relation to the aspects related to their culture of innovation. So, a cultural diagnosis is required to understand their current moment, their strategy and to create aligned action plans to guide cultural transformation when necessary (Migueles *et al.*, 2011).

Currently, there are several studies on the elements that make up the innovation culture and the best ways to diagnose it (Danks *et al.*, 2017; Rao and Weintraub, 2013; Scherer and Carlomagno, 2016). However, the amount of studies makes it difficult to understand the phenomenon as a whole, as well as its application. Thus, it would be ideal to have a systematized instrument that would group the main concepts of innovation culture, eliminating redundancies and presenting a user-friendly application.

In this way, this work aims to study the main elements found in the academic and gray literature and to propose a systematized instrument for diagnosing an organizational culture of innovation. Complementary, a pilot application was carried out in order to check the viability of the instrument. Therefore, the general objective of this work is to develop a systematized instrument for diagnosing the main elements of innovation culture.

The conduction of the research method was based on a literature review of the culture of innovation and its related topics. Finally, using content analysis (Bardin, 2016), a Systematized Instrument was built to diagnose the culture of innovation. This instrument was applied in a company (Innovare Healthcare - fictitious name) in the healthcare sector, in a pilot case, to analyze the results and test the functionality of the solution. This instrument should make the diagnosis of innovation culture more practical and comprehensive.

After this Introduction section, this paper presents in next section the Literature Review with the concepts that guided the construction of the Systematized Instrument for the Assessment of Culture of Innovation, followed by the Research Methodology adopted, together with the description of the pilot application in a company. The results of the diagnosis and the

Systematized Instrument can be found in the Results and Discussion section, which precedes the Conclusions of the work. Finally, the References.

LITERATURE REVIEW

While innovation is a concept that is much desired by organizations, at the same time it is not widely known and worked appropriately (Scherer and Carlomagno, 2016). Cultural aspects are premises for innovation (Benchmarking Innovation Impact, 2019; De Bes and Kotler, 2011). The organizational culture of an organization is the guideline assumed to be true by people and can impact the company's results (Cameron and Quinn, 1999; Schein, 1984).

It is possible to diagnose an organizational culture among the four groups defined by Cameron and Quinn (2011): Clan, Adhocracy, Hierarchy and Market. The relationship between groups requires a cultural trade-off between conflicting values. The Organizational Culture Assessment Instrument (OCAI) is an instrument based on six dimensions that assess people's current and desired perception of an organization, resulting in the distribution of 100 points among the four mentioned cultural groups (Cameron and Quinn, 2011). The diagnosis of an organizational culture can reveal the company's global trend in relation to the culture of innovation, but it is possible to deepen this analysis through the elements of innovation **(**see Chart 1**).**

Chart **1 -** Synthesis of the analyzed instruments

Instrument	Description	Questions	Reference
Organizational Culture Assessment Instrument (OCAI)	It quantifies the current and the desired organizational culture using trade offs between conflicting values	6 questions evaluated in the current and in the desired situations	Cameron and Quinn (2011)
Innovation Octagon	It assesses 8 dimensions of innovation, not just culture	24 questions	Scherer and Carlomagno (2016)
Innovation Quotient (IQ)	It quantifies 54 elements of innovation culture in 6 dimensions	54 questions	Rao and Weintraub (2013)
Innovation Quotient Adapted	It is an improvement of the previous instrument, but using only the questions that were validated statistically	37 questions	Danks et al. (2017a, b)

Source: elaborated by authors.

The culture of innovation is an oriented set of shared values and practices in favor of innovation (Dobni, 2008). According to Rao and Weintraub (2013), it is possible to distribute aspects of the innovation culture among six different blocks: Values, Behaviors, Climate, Resources, Processes and Success. Within these values, it is still possible to subdivide into factors and elements of innovation. In the study carried out by Danks *et al.* (2017a, b), the authors statistically validated 37 of the 54 values proposed in the instrument called Innovation Quotient (IQ), in which innovation elements are evaluated, according to people's perception of their manifestation in business daily life.

Scherer and Carlomagno (2016) developed the Innovation Octagon, which is a tool that helps both the diagnosis of innovation potential and the design of management practices to improve its performance. It presents the 8 dimensions of innovation management: Strategy; Culture; Leadership; People; Structure; Process; Funding and Relationships.

The Innovation Octagon presents a balanced set of aspects necessary for the management of innovation. There are 24 questions divided into 8 dimensions with 3 questions. It is a tool that assists in the diagnosis of innovation potential as well as the design of management practices to improve their performance (Scherer and Carlomagno, 2016).

The innovative culture exists in the DNA of innovative companies, so it spreads out throughout the whole organization. Continuous innovation is intrinsic and pervasive among all involved and it is essential to sustain innovative processes within an innovative organization. Thus, innovative behaviors will sustain processes that impact the company's performance (Hogan and Coote, 2014).

As shown in the previous paragraphs, many studies focus on describing the innovation culture through the elements or dimensions that represent its main characteristics. Therefore, it can be said that these studies work with the different aspects of the innovation culture (Danks et al, 2017).

RESEARCH METHODOLOGY

The methodology used in this research is divided into two stages: a) literature review with content analysis to build a Systematized Instrument for the Assessment of Culture of Innovation; and b) description of the method of application and evaluation of this instrument in a pilot application at the company Innovare Health (fictitious name used due to confidentiality issues), which took place together with the application of the OCAI.

INSTRUMENT DEVELOPMENT

Considering that there are several models currently used (see Chart **1** with examples of the models used in this research), this study proposes to develop a unified and systematized instrument that allows for a more comprehensive diagnosis. The following steps were carried out in the elaboration of this proposal: a) identify the current diagnostic models; b) select the most relevant elements; and c) systematize the elements into a unified instrument.

The identification of instruments was conducted through the process of exploratory literature search, such as: scientific articles, books and journal publications, consultancies and internet pages. The literature review includes both the theoretical aspects necessary to build a bibliography that serves as a basis for an analysis of its content (Rowley and Slack, 2004 as cited in Dionisio, 2019).

Bardin (2016) claims that a classification begins with the individual analysis of a concept followed by the search for its grouping based on its semantics compared to the other concepts. Therefore, each question or element contained in these instruments was analyzed individually, in order to verify the criteria that it seeks to evaluate such as its relevance within the group (content analysis). Then, we seek to determine a minimal number of questions capable of representing other questions in each group. Finally, these questions were classified into dimensions that include concepts that have common interfaces.

APPLICATION IN A COMPANY IN THE HEALTHCARE SECTOR

Innovare Healthcare is a medium-sized company, located in the State of São Paulo/Brazil. It was founded in the 70's and has about 300 employees. The company's mission is focused on generating accessibility in the healthcare market. To validate the systematic proposed in this project, the OCAI and the Systematized Instrument proposed in this work were applied in the year 2020.

For both questionnaires, the respondents received, along with the survey link (questionnaire available online), an introduction in which the objectives of the process were described, as well as considerations about the confidentiality of individual responses (Informed Consent Form). After the application of the instruments, the questionnaires requested demographic data regarding the position, department, age group, time working in the company, leadership time (if applicable), gender and education level. The purpose of these questions was to allow a segregated analysis of the responses, respecting the confidentiality criterion of individual responses, with no intention of identifying individual respondents. The particularities of each questionnaire are described below, as well as the analysis format for each one.

- *ORGANIZATIONAL CULTURE ASSESSMENT INSTRUMENT (CAMERON AND QUINN, 2011)*

The purpose of applying the OCAI was to understand how the innovation (adhocracy) culture of the company could be compared to other types of organizational culture (group, competition and control). The evaluation of the OCAI results is done through the arithmetic mean between the answers. For each of the six dimensions, the respondent distributes 100 points among 4 alternatives. In all dimensions the following relations are valid:

- Alternative A: Clan / Group Culture
- Alternative B: Adhocracy / Innovation Culture
- Alternative C: Market / Competition Culture
- Alternative D: Hierarchy / Control Culture

Therefore, to find the global result of a group for one of its situations (current perception or desired perception) it is necessary to calculate the arithmetic mean among the six answers of the alternative referring to the desired culture. Thus, the overall result of the OCAI has eight different values: the four averages of the cultural groups (Clan, Adhocracy, Market and Hierarchy) for each scenario (current or desired). For this work, only the global results of OCAI will be presented (to identify aspects of the organization's culture), directing more detailed presentations of the Systematized Instrument (focus of this research).

- *SYSTEMATIZED INSTRUMENT*

The application of our Systematized Instrument took place online and also allowed respondents to assess the application of the instrument through questions about the extension of the instrument, the difficulty of understanding the questions, in addition to an open question for feedback (optional).

The evaluation of the results of the Systematized Instrument is performed through the arithmetic mean between the answers (for each of the six dimensions that will be presented in the next session). Therefore, to find the global result of a group, it is necessary to calculate the arithmetic mean between the answers of the questions that make up a dimension. With this, the global result of the Systematized Instrument is formed by a set of values in the same quantity as its dimensions.

Since Y is the answer of the i-th respondent out of a total of N responses, we have that the average of the dimension $\underline{Y}_{\text{Dimension}}$ can be calculated as:

$$\bar{Y}_{Dimension} = \frac{\sum Y_i}{N}$$

Since $\underline{Y}_{\text{Dimension}}$ the average of responses from the j-th dimension of a total of M dimensions, we have that the average of innovation culture points ($\underline{Y}_{\text{Innovation}}$) can be calculated as:

$$\bar{Y}_{Innovation} = \frac{\sum \bar{Y}_{Dimension\,j}}{\mathrm{M}}$$

With this, it is possible to arrive at the value of $\underline{Y}_{\text{Innovation}}$ that represents a global indicator of the result of the diagnosis of the Systematized Instrument, ranging from 1 (very low culture of innovation) to 5 (very high culture of innovation).

RESULTS AND DISCUSSION

This topic is divided into two sections: construction of the Systematized Instrument and results of its application; and overall results of the application of OCAI.

INSTRUMENT DEVELOPMENT

Using the references studied through the proposed method, this topic presents the construction of the Systematized Instrument for the Assessment of Culture of Innovation.

- *ASSESSMENT OF THE ELEMENTS OF INNOVATION*

The identification of the most relevant elements among the innovation culture diagnoses was inspired by the elements of the IQ (Rao and Weintraub, 2013) associated with a content analysis of all the issues involved in the other instruments mentioned in this work. Thus, 38 questions were adapted to propose the Expanded Innovation Culture Questionnaire (our main contribution of this paper) based on the concepts proposed in the original instruments. When answering the questionnaire, participants were instructed to rate each question in their organization on a Likert scale from 1 (it never happens) to 5 (it is always true).

After the content analysis of each element and questions, a rewriting was proposed. With this, it sought to make the issues easier to understand, by removing technical terms and ambiguities of interpretation. Chart **2** presents the final description of the elements and questions.

Chart **2 -** Elements and Questions of the Systematized Instrument

Element	**Questions**
Adapt	Our leaders know how to adapt according to the context.
Ambiguity	We tolerate conflicting opinions when seeking new opportunities.
Autonomy	The workplace gives us the freedom to pursue new opportunities.
Capabilities	We have developed new skills in recent years due to innovation projects.
Customers	Our customers think of us as an innovative organization.
Communication	We work with collaborative tools for innovation.
Community	We know how to debate concepts and innovation projects clearly.
Competitors	We are more innovative than other organizations in our business.
Confidence	We are true followers of our values.
Challenge	Our leaders challenge us to act and think entrepreneurially.
Money	We have finances applied to the search for new opportunities.
Discipline	Our innovation processes are aligned with the organization's strategy.
Fun	We like to be spontaneous and we are not afraid to laugh at ourselves.
Diversity	We respect the differences that exist in our organization.
Ecosystem	Customers and/or suppliers participate in our innovation system.
Scale	We invest quickly in initiatives that are well accepted by the market.
Space	We have physical and/or virtual space dedicated to the search for new opportunities.
Specialists	We have access to innovation experts who can support our projects.
Experimentation	Our processes allow us to try new things.
Smart failure	We quickly stop projects based on predefined error criteria.
Failed OK	We are not afraid of failure and we use mistakes as lessons.
Finance	Innovation has led us to better financial performance than our competitors.
Flexibility	Our processes are flexible according to the context.
Voracity	We have a burning desire to explore opportunities.
Imagination	We encourage new points of view.
Influence	Our leaders use their influence to innovate.
Initiative	Everyone takes proactive initiatives to innovate.
Model	Our leaders are role models of innovative behavior.
Action oriented	We are quick to seize promising market opportunities.
Accountability	We take responsibility for our own actions and avoid blaming others.
Prioritize	We prioritize innovation opportunities by assessing their risk.
Purpose	Innovation is a long-term strategy.

Prototype	We test our solutions quickly and cheaply.
Reward	We reward people for the initiative to innovate.
Selection	We hire people with an innovative profile.
Time	We have time to look for new solutions.
Decision making	We work on innovation in a disciplined way.
Teamwork	Our teamwork is great.

Source: elaborated by authors.

The new proposal for explaining the criteria allows for a less subjective analysis of the respondent, as it reduces the level of abstraction of the previous scale, associating the answers with the respondent's perception of organizational routine facts. After the answers, it was possible to assess the respondents' perception of the cultural aspects of innovation in their organizations.

- *CLASSIFICATION OF ELEMENTS IN DIMENSIONS*

As a way of summarizing some information, the questions underwent a second content analysis, in order to group elements that concern related topics. From this analysis, a six-dimensional model was proposed for the elements of the Systematized Instrument (Chart **3**).

Chart **3 -** Dimensions for Analysis of the Systematized Instrument for the Assessment of Culture of Innovation

Dimension	**Explanation**
Values	Values drive priorities and decisions, reflected in the way a company spends its time and money. A company's values are not what top management indicates in reports, but the guidelines that guide decision-making on a daily basis. Values are manifested in the way people behave and spend, rather than the way they speak.
Behaviors	Workplace life is nurtured by engaged and enthusiastic people. People have the security to be challenged and to take risks for the sake of organizational learning.
Leadership	Senior management must be committed to a culture of innovation. More than leading, these people must be agents of transformation and facilitators of processes and projects, sponsoring innovative actions.
Processes	Patterns of interaction, coordination, communication and decision-making that people use to transform resources into products and services of greater value, that is, the way the company generates new ideas, evaluates them, tries them and selects which ones to invest in.
Resources	Resources involve people, systems and projects. Innovation resources represent the company's ability to support its innovation through tangible (money) and intangible (knowledge) aspects.
Results	Successes in three spheres: external, business and personal. Success is feedback that feeds back to the other dimensions. It represents the perception that people have about the impact caused by innovation in the three spheres. Positive feedback reinforces the value that innovative actions had in the other dimensions.

Source: elaborated by authors.

For each dimension, a set of elements already identified was associated, forming all dimensions of the culture of innovation. Therefore, the questions proposed in the model are divided between these six dimensions, allowing a macro analysis of the answers of complementary concepts. In this way, the distribution of the selected elements among the dimensions allows the development of the Chart **4**.

Chart **4 -** Elements in each Dimension

Dimension	Element	Dimension	Element
Behaviors	Communication	Resources	Money
	Community		Ecosystem
	Fun		Space
	Diversity		Specialists
	Accountability		Selection
	Teamwork		Time
Leadership	Adapt	Results	Capabilities
	Challenge		Customers
	Influence		Competitors
	Model		Discipline
Processes	Scale		Finance
	Experimentation		Reward
	Smart failure	Values	Ambiguity
	Flexibility		Autonomy
	Action oriented		Confidence
	Prioritize		Failed OK
	Purpose		Voracity
	Prototype		Imagination
	Decision making		Initiative

Source: elaborated by authors.

Furthermore, it is possible to notice that there is a relationship flow (cause-and-effect) between the dimensions. As shown in Figure **1**, the Values, Behaviors and Leadership dimensions have a causal relationship to the Resources and Processes dimensions. These two have the same relationship with the Results dimension. The opposite direction concerns a feedback relationship, that is, good results will reinforce the results obtained in the previous dimensions.

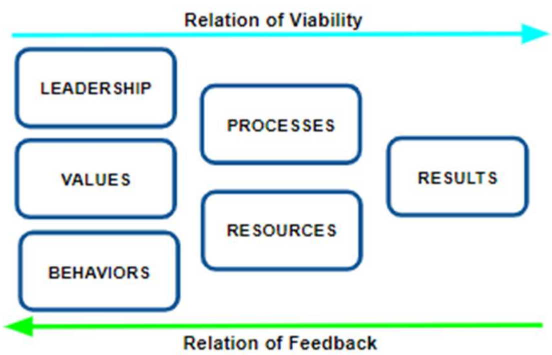

Figure **1 -** Dimension Relationship Diagram
Source: elaborated by authors.

Example: the elements "Initiative" (Values), "Communication" (Behaviors), "Challenge" (Leadership) enable the elements "Ecosystem" (Resources) and "Action Oriented" (Processes), which consequently allow, for example, the growth of the "Finance" element (Results). In the opposite direction, the good results in this last element will reinforce the action-oriented processes in a positive way, in addition to stimulating the integration of the innovation ecosystem. The same will happen in other relationships. Reinforced action-oriented processes will confirm the success of previous elements, and so on.

APPLICATION IN A COMPANY IN THE HEALTHCARE SECTOR

Below are the results of the application of the instruments at Innovare Health. The global results obtained in the application of the OCAI will be presented and, in sequence, the results obtained for the Systematized Instrument for the Assessment of Culture of Innovation. Finally, a topic with feedback from respondents about the systematized instrument is presented. It is worth noting that the application of the instruments took place during the Covid-19 pandemic in 2020 and that the impact that it may have had on the results was not evaluated exclusively.

- OCAI

The questionnaire was answered by 108 people (approximately 35% of the company's employees), 29 of them from management (61% of the total number of managers). The questionnaire was proposed by the internal project group and participation was voluntary. At the beginning of all questionnaires, respondents were informed of the project's objectives and the confidentiality of individual responses.

The OCAI Diagnostic Tool was applied to support this project in order to facilitate the visualization of the OCAI results. It is possible to analyze that the organization has as its current perceived culture an explicit focus on Clan Culture, with a secondary focus on Hierarchy. The desired culture perception profile, however, points to a shift in secondary focus. Instead of Hierarchy, there is a desire for a significant increase in elements of an Adhocratic culture.

Before proceeding, it is worth noting the fact that the overall result is a simple average of all responses. Considering that 27% of the answers belong to managers, this global result shows a closer view of the general public (non-managers) of the company.

In conclusion, OCAI reveals that there is a perception of the presence of Clan Culture and Hierarchy spread across departments and positions. There is a global tendency to desire cultures such as Adhocracy and Market, but there is no global alignment in this regard. As one of the focuses is the Adhocracy culture, the study of the culture of innovation in greater detail is necessary to support a possible plan for cultural transformation. Thus, our systematized instrument contributes toward this goal.

- *SYSTEMATIZED INSTRUMENT FOR THE ASSESSMENT OF CULTURE OF INNOVATION*

In the application phase of the 38 questions of the Systematized Instrument, a total of 86 responses were collected, with 35 responses from the company's managers. Starting the analysis from the defined blocks and for the general public of the company, Figure **2 (Part A)** represents the average of the scores of the questions of each dimension. It is worth remembering that the scale used was from 1 to 5, with 3 being the midpoint.

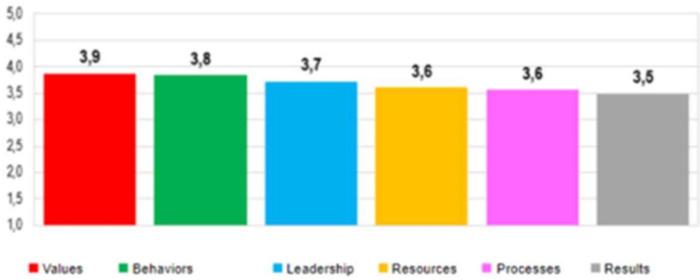

Figure **2 (Part A) -** Average by Dimension (General Public)
Source: elaborated by authors.

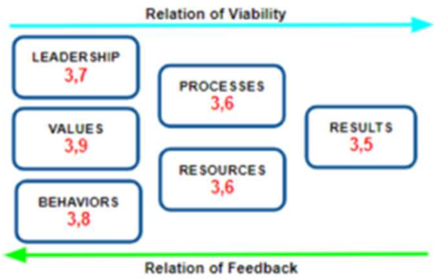

Figure **2 (Part B) -** Relationship between Dimensions with Averages
Source: elaborated by authors.

Using these data, the global average of the company is determined through the arithmetic mean between the values of each one of the dimensions. Thus, the overall result of Innovare Health was 3.7 points. The result represents 67% of the possible total.

In Figure **2 (Part B)**, there is an indication of the relationship between the viability of the innovation culture. The company presents a distribution of answers that, in the long term, makes sense according to an innovation strategy. The Values, Behaviors and Leadership dimensions present the highest results, enabling the following dimensions: Resources and Processes. The Results dimension is the lowest, and this confirms the relationship proposed in this project. The results will only be noticed after the consolidation of the other dimensions, allowing the innovation to generate and recognize its results.

Going into the details of the questions in general, Figure **3** shows the average reached by each question, highlighting its dimensions.

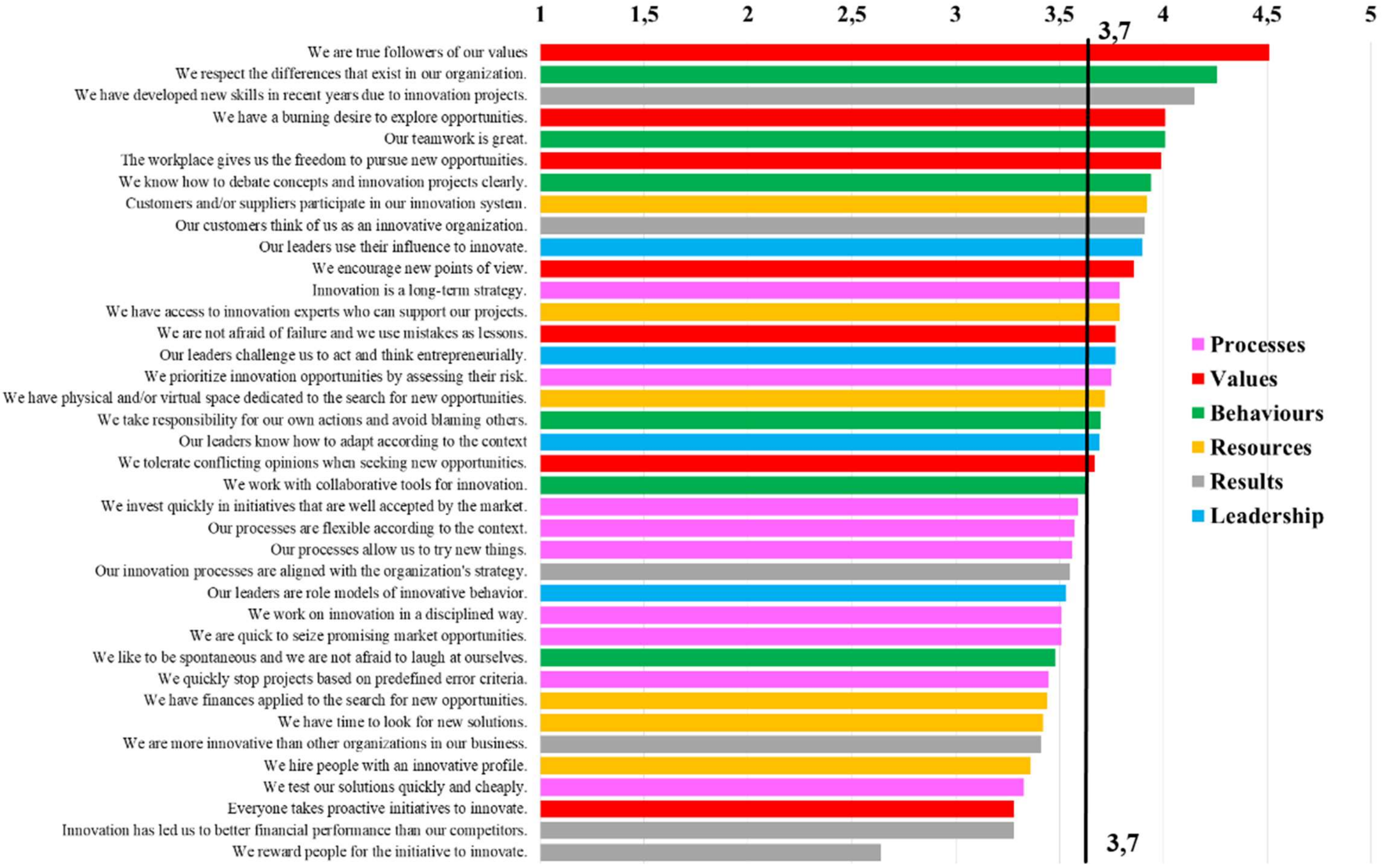

Figure **3 -** Result by Question of the Systematized Instrument (General Public)
Source: elaborated by authors.

Considering the general public, it is possible to note the following points:

- Values Dimension: a) The company considers itself true to its values; and b) There is a perceived lack of proactivity on the part of people;
- Behaviors Dimension: a) Respect is a value well evaluated by the respondents; and b) Although they work well as a team, there is no use of collaboration tools;
- Leadership dimension: Leaders are considered influential in favor of innovation;
- Resources Dimension: a) There are innovation specialists in the company, although the people hired do not have an innovative profile according to the answers; b) there is a perception that the company does not invest much in new opportunities related to innovation;
- Processes Dimension: a) Innovation is seen as a long-term strategy; b) Lack of agility in innovation processes, which could also be more disciplined; and
- Results Dimension: a) People recognize that they have developed new innovation skills in recent years; b) The customers' view is positive about the company's innovation in the respondents' perception; c) The company's financial performance is not evaluated

positively; and d) Respondents do not feel adequately rewarded for practicing innovation.

Among these points, there is a strong negative highlight for the issue of rewards, which is the only one with an average below 3 points. Among the positive highlights, it is important to note that in general (with exceptions) the Values and Behaviors dimensions had all their questions among the best evaluated.

One last noteworthy mention is regarding the question where people recognize that they understand more about innovation due to the actions of the last few years. This point can reinforce, for example, a long-term strategy for innovation. People have knowledge about the importance that is necessary to develop leaders, to build new behaviors and to seek or distribute resources in a more appropriate way in view of the concept of a culture of innovation.

In conclusion, the results obtained by Innovare Health point to a culture of growing innovation, although far from ideal. Several points proved to be limiting factors for the culture, as the following examples show: low global average; bad perception of managers regarding the innovative culture; lack of knowledge about resources and results regarding innovation; long-term strategy; agility; rewards for innovation and a Research, Development & Innovation (RD&I) team critical to innovation. Due to all these factors, the company presented limitations in its analysis, reaching a result that, although it can be classified as “Good”, has many opportunities for improvement.

- *FEEDBACK ABOUT THE SYSTEMATIZED INSTRUMENT FOR THE ASSESSMENT OF CULTURE OF INNOVATION*

At the end of the application of the Systematized Instrument, the respondents evaluated the questionnaire. Questionnaire length and comprehension difficulties were evaluated. Figures **4** and **5** show these results, respectively.

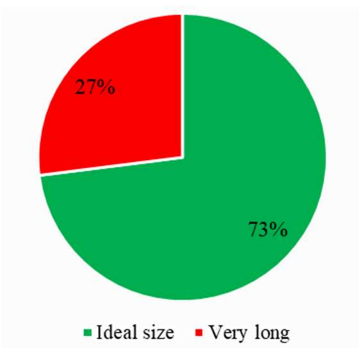

Figure **4 -** Assessment on the Size of the Questionnaire
Source: elaborated by authors.

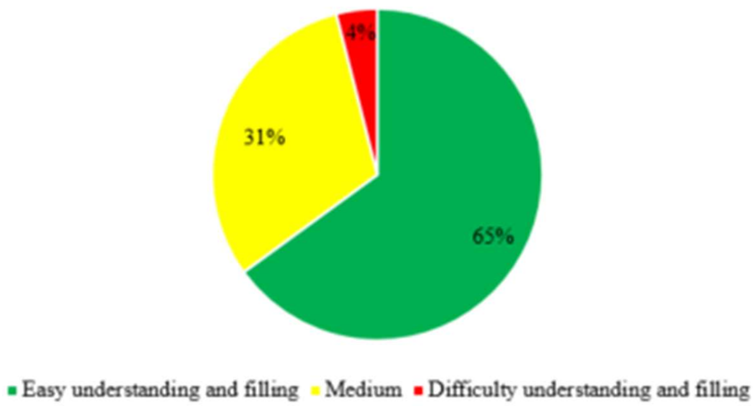

Figure **5 -** Assessment of Difficulty in Understanding the Questions of the Systematized Instrument
Source: elaborated by authors.

Finally, there was also an open (optional) feedback for the participants. The following topics summarize the information highlighted from respondents' comments.

- Positive points addressed: dynamics of the questionnaire, feeling of involvement of people, interesting content for respondents, ease of answering using the platform.
- Negative points: long introduction (appeared in the response of three participants), lack of knowledge of company data, confusing alternatives, lack of objectivity in the alternatives, excessive amount of questions, redundancy of some questions, missing a question about employee appreciation.
- Suggestions: organize questions into categories, remove demographic questions to encourage sincerity of answers.

From the results of this topic, it is possible to infer that the difficulty of understanding the questionnaire was evaluated positively, with only 4% of negative opinions. This result confirms the importance of the systematized instrument, which makes reading the questions and understanding the questionnaire more simplified, without losing its concept load. Even so, there is an opportunity for improvement in terms of the extension of the questionnaire. More than a quarter of people rated the instrument as extensive. The suggestions to explore redundancies and organize the questions emerge as alternatives to improve this result. The issue of employee appreciation is linked to the Results dimension, mainly individually and can be evaluated in future studies.

Finally, it is necessary to work on the introduction of the questionnaire, which brought the objectives, expectations and topics of confidentiality to the respondents, but in an extensive way. This displeased some of the people and may have influenced the responses, such as the apparent length of the questionnaire.

CONCLUSIONS

The general objective of this project was to propose a Systematized Instrument for the diagnosis of innovation culture using as a basis the concepts, elements and instruments present in the literature. It was also proposed to apply the instrument in a company in the healthcare sector to test the pilot version of this Systematized Instrument. Through the literature review, followed by content analysis and categorization, it was possible to define the elements, with 38 questions being applied. From them, questions and dimensions were constructed that allowed the elaboration of the Systematized Instrument for the Diagnosis of the Culture of Innovation, such as its evaluation method. This instrument presented a more comprehensive assessment of all elements and with fewer questions than the other instruments.

The instrument was applied together with the OCAI in a company in the healthcare sector. The first diagnosis pointed to a company that is not perceived as a form of an Adhocracy (innovative) culture in the current scenario, but there is a desire to expand this result in a future scenario. This result enabled the application of an innovation culture instrument, as it could help to understand in detail the aspects of the cultural change journey that will lead the company to have a culture of innovation in the future.

The results of the Systematized Instrument diagnosis brought visibility to factors that limit the culture of innovation, whether in the company as a whole (as proactive), or in specific positions and departments. Identifying the different perceptions of the dimensions and elements of innovation could contribute to a personalized and aligned approach to cultural change, reducing potential resistance. The model of relationship between dimensions was reinforced by the result, which pointed to good results in the initial dimensions (Values, Behavior, Leadership) of the cause-and-effect flow. Taking into account the temporality of cultural changes, we have an expectation that these results will enable the growth of the final dimensions if the cause-and-effect flow is really true. For Innovare Health, the application of this study in a timely manner may help to evaluate the performance of the actions of its action plan and also to review the organizational strategy.

As a form of continuity, this project allows replicating its model to associate it with other instruments that may exist. Our hypothesis regarding cause-and-effect among the dimensions should also be tested. Finally, a mass application can assess the statistical relevance of the results and dimensions, which can reinforce this study or bring opportunities for improvement.

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REFERENCES

Bardin, L. (2016), Análise de conteúdo, Edições 70, Coimbra.

Benchmarking Innovation Impact (2020), "Benchmarking Innovation Impact", Amstelveem: KPMG LLP, available at: https://info.kpmg.us/content/dam/info/en/innovation-enterprise-solutions/pdf/2019/ benchmarking-innovation-impact-2020.pdf. (accessed 27 May 2020).

Cameron, K.S. and Quinn, R.E. (1999), "Diagnosing and changing organizational culture", Jossey-Bass, San Francisco.

Cameron, K.S. and Quinn, R.E. (2011), "Diagnosing and changing organizational culture", 3rd ed, Jossey-Bass, San Francisco.

Danks, S., Rao, J. and Allen, J.M. (2017), "Measuring culture of innovation: a validation study of the innovation quotient instrument" (Part 1), Performance Improvement Quarterly, Vol. 29, No. 4, pp. 427-454.

Danks, S., Rao, J. and Allen, J.M. (2017), "Measuring culture of innovation: a validation study of the innovation quotient instrument" (Part 2), Performance Improvement Quarterly, Vol. 30, No. 1, pp. 29-54.

De Bes, F.T.T.T. and Kotler, P. (2011), "A Bíblia da inovação: princípios fundamentais para levar a cultura da inovação contínua às organizações", LeYa, São Paulo.

Dionisio, G.F. (2019), “Análise dos elementos que compõem a cultura de inovação: um estudo teórico”. Tese (Mestrado) - Escola de Engenharia de São Carlos, Universidade de São Paulo, São Carlos.

Dobni, C.B. (2008), “Measuring innovation culture in organizations: the development of a generalized innovation culture construct using exploratory factor analysis”, European Journal of Innovation Management, Vol. 11, No. 4, pp. 539-559.

Hogan, S.J. and Coote, L.V. (2014), “Organizational culture, innovation, and performance: a test of Schein’s model”, Journal of Business Research, Vol. 67, No. 8, pp. 1609-1621.

Migueles, C., Zanini, M.T. and Gomes, A.S. (2011), “Sua empresa já fez diagnóstico de intangíveis?”, HSM Management, Vol. 85, pp. 31-37.

Rao, J. and Weintraub, J. (2013), “How innovative is your company’s culture?”, MIT Sloan Management Review, Vol. 54, No. 3, pp. 29-37.

Rowley, J. and Slack, F. (2004), “Conducting a literature review”, Management Research News, Vol. 27, No. 6, pp. 31-39.

Schein, E. H. (1984), “Coming to a new awareness of organizational culture”, Sloan Management Review, Vol. 25, No. 2, pp. 3-16.

Scherer, F. O. and Carlomagno, M. S. (2016), “Gestão da inovação na prática: como aplicar conceitos e ferramentas de inovação para alavancar a inovação”, 2nd, Atlas, São Paulo.

Quality Management in R&D organizations: a literature review

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ABSTRACT

Purpose: The role of R&D organizations in innovation contributes to economic and social development. This paper examines documents about quality management systems applied in R&D organizations taking into account the ISO 9001 standard. The purpose of this work is to identify the potential for further research concerning quality management, in this case, based on ISO 9001, in R&D organizations. **Design/methodology/approach:** this literature review explores the issue from a bibliographic search at the Scopus database. In order to select only relevant publications, a qualitative filter was applied to the data collection by analyzing titles, abstracts, and contents. **Findings:** From 2015 to 2021, 121 articles were found in Elsevier Scopus. Ten articles are significant after skimming the results. In this set of documents, research concerning quality management systems based on ISO 9001 standards in R&D organizations is reviewed. Even ten publications reveal the potential to explore further and this literature review presented four categories of work. This is a sign that more research has to be done to paint the picture of quality management in R&D organizations. **Research limitations/implications:** the scope of the study is restricted to reviewing articles from the Scopus database from 2015 to 2021. **Originality/value:** this paper points out an interesting avenue for future exploration in R&D organizations. Most studies analyze quality management systems, mostly based on ISO 9001, but few examine R&D organizations, which are complex in nature.

Keywords: Quality Management, Quality Management System, QMS, R&D, ISO 9001.

Paper type: Literature review.

INTRODUCTION

Quality Management Systems (QMS) is an important research issue. ISO 9000 standards have resulted since 1987 in a significant worldwide phenomenon, given the quite impressive growth and diffusion of registrations according to the ISO 9001 standard in so many countries and different kinds of organizations (Sampaio et al., 2009a). There is no comparison between the number of valid ISO 9001 certificates and other standards like ISO 14001 standard, ISO 45001 standard or any management standard published by the International Standard Organization (ISO). ISO does not perform certification to its standards, does not control certification performed independently of ISO by other organizations, however, created The ISO Survey to answer frequent requests for information on the number of certificates that have been issued (Psomas and Fotopoulos, 2009). The ISO Survey 2020 data presented in Table 1 shows the top five valid certificates per standard. A valid certificate is one that has been issued by a certification body accredited by IAF MLA members during the year of the survey or in the two years preceding it that is still valid on 31 December of the year of the survey (ISO Survey, 2020).

Table 1 – the top five valid certificates per standard.

	Total valid certificates	**Total number of sites**
ISO 9001	916.842	1.299.837
ISO 14001	348.473	568.798
ISO 45001	190.481	251.191
ISO/IEC 27001	44.499	84.181
ISO 22000	33.741	39.894
Others 07 standards	58.995	103.890

ISO 9001 standard is the most widely used quality management system in organizations globally. The ISO 9001 standard diffusion has been studied by several authors (Sampaio et al. 2009a; Sampaio at al. 2009b; Llach at al., 2011; Guler et al., 2002; Corbett, 2006). ISO 9001 certification represents a worldwide phenomenon and if this standard is correctly implemented and understood, as opposed to being used just as a marketing and promotional tool, there seem to be significant benefits, internal and external ones (Sampaio et al. 2009b). Llach at al. (2011) analyzed the evolution of the worldwide diffusion, according to industrial sectors of activity, of the ISO 9000 family of quality standards. Studies of economic sectors such as Llach at al. (2011) are relevant since diffusion is not uniform among all agents. Despite the fact that ISO 9001 certification represents a worldwide phenomenon and the diffusion studies carried out, there is a gap among R&D (Research and Development) organizations. Even The ISO Survey is unable to capture the distribution of ISO 9001 standards among R&D organizations.

This work seeks to explore the application of the ISO 9001 standard in R&D organizations. These organizations carry out R&D activities that include basic research, applied research, and experimental development and it's increasingly viewed as an input to innovation in the context of the overall efforts made in a knowledge-based global economy (OECD, 2015). R&D organizations conduct activities within one or more economic sectors and at least one knowledge area. R&D organizations also transfer knowledge that helps companies to improve their processes or products or to develop new processes or products. Sampaio et al. (2009a) present the definition of Eurostat for innovation activities like those carried out by organizations that introduce new or significantly improved (goods or services) to the market or those that implement new or significantly improved processes.

Innovation has been a major concern for researchers and professionals, as the literature provides conflicting theoretical arguments on the relationship between total quality management and innovation (Pinto, 2020). The relationship between standards and innovation has been studied by several authors, showing that standardization is a valuable tool to drive innovation (Di Luozzo at al., 2020). Sampaio et al. (2009a) bring based on their data analysis an inverse relationship between ISO 900 certification and IMD (Institute for Management Development Competitive Index). Interestingly, the authors of the same study assert that, for some countries, there appears to be a positive correlation between the number of companies that are certified and the number of companies that are involved in innovation activities. The foregoing points emphasize the need for further research into quality management in R&D organizations once they are incorporated into global innovation efforts.

An analysis of the impact of a QMS on innovation could also be carried out on R&D organizations. It's important to investigate if QMS has a positive or a negative influence on R&D organizations' outcomes and which quality management standard, model, program or tool enhances its results. Through a literature review, this study explores the state of the art of publications regarding quality management in R&D organizations according to ISO 9001 standards. Due to the certification process, this project was designed using the ISO 9001 quality management system. Certification is the provision by an independent body of written assurance (a certificate) that the product, service or system in question meets specific requirements (ISO, 2022). In other words, ISO 9001 certification can be used to demonstrate to outsiders that an effective management system is in place at an organization.

As pointed out before, R&D organizations are important to innovation, economic and social growth and quality management could help to increase its results. The quality of R&D could be expressed in terms of reliability and reproducibility and quality management could be a response to this problem of R&D organizations. According to Sené, Gilmore and Janssen (2017) many column inches have been dedicated to discussing this 'reproducibility crisis' in scientific research According to Liguori and Kisslinger (2021) the implementation of Quality Management (QM) tools can be extremely valid for scientists to face the increasingly competitive that requires researchers to continuously improve and enhance their performance, raising issues like reliability and reproducibility of the data as well as standardization of the methodologies. However, as pointed out by Vermaercke (2000) and Vré (2000), the implementation of quality assurance (QA) in research and development (R&D) laboratories is much rarer and remains a highly controversial issue.

RESEARCH METHODOLOGY

Sampaio et al. (2009b) conduct a literature review of ISO 9001 studies which are sorted in six categories after approximately 100 documents analysis. This work adopted a similar methodology that aims to find key elements regarding quality management systems conforming to ISO 9001 in R&D organizations. It is important to note that at the time that the authors conducted their study, a different version of ISO 9001 was in force in a different lifecycle period. This work design takes into account aspects of the ISO 9001:2015 lifecycle. A literature review is conducted using bibliometrics and document analysis. According to Troian & Gomes (2020), bibliometrics make it possible to build a map of the knowledge structure of a particular field and the steps can be described in Figure 1.

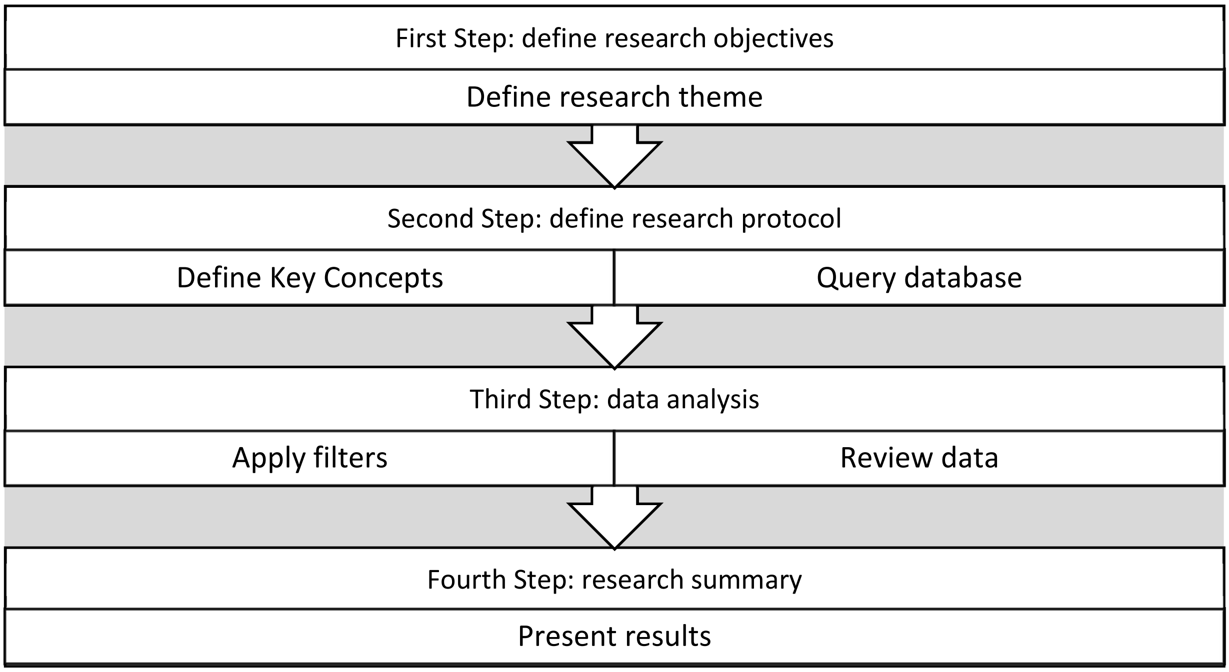

Figure 1 – Steps for the bibliometric research, adapted from Troian & Gomes (2020)

The choice of the theme quality management system based on ISO 9001 in R&D organizations accomplishes the first step of this research methodology, defining the research theme. The ISO 9001 standard is one of the standards that could be adopted by R&D organizations. ISO 9001 is one model of quality management system. There are other models or standards to explore quality management in R&D organizations.

The second step has two minor steps: define key concepts and the query database. The choice of Scopus database and the definition of search query comply with the second step. Scopus is considered to be the biggest multidisciplinary peer-reviewed literature database that provides several research and analysis tools that allow for a series of filters to fine-tune the publications shown (by timeframe, type of publication, language, area of interest, and others) (Troian and Gomes, 2020).

Mainly concepts regarding the theme expressed in simple or compound keywords were organized into three different categories. These categories compose the query used in this research as Table 2.

Table 2 – Key Words and search structure used in Bibliometric research (Troian & Gomes, 2020)

<table>
<tr><td>Axis 1 – Key Words</td><td>Axis 2 – Key Words</td><td>Axis 3 – Key Words</td></tr>
<tr><td>ISO 9001; 9001</td><td>Quality; quality management; quality management systems; QMS</td><td>research center; technological institute; research institute; R&D; institute of technology; RDI; institute of research; Technology Research</td></tr>
<tr><td colspan="3">Search query</td></tr>
<tr><td colspan="3">"ISO 9001" OR "9001"
AND
("Quality"; "quality management"; "quality management systems"; "QMS")
AND
("research center" OR "technological institute" OR "research institute" OR "R&D" OR "institute of technology" OR "RDI" OR "institute of research" OR "Technology Research")</td></tr>
</table>

The third step consists of two minor steps: applying filters and reviewing data. This study examined documents filtered by year from 2015 to 2017. The selection of this timeframe was made based on the year of the current version of the ISO 9001 standard. It is important to explore the research state for this standard in this very heterogeneous sector. The period may be shortened due to the transition period, all the time and effort required to implement a quality management system based on the 2015 ISO 9001 version, to improve processes with the use of specific tools, and finally, all the time and effort required for publishing. Although, the 2015 version of ISO 9001 is so different from the previous one that a literature review in a longer timeframe would not strengthen the work. In addition, the type of publication was filtered so that only papers published in conferences, articles, or reviews were taken into consideration. In a second filter, the stage of publication, as well as the language of the document, were considered, taking into account the final stage and English.

The last step was to apply a qualitative filter to the data collection through the analysis of title, abstracts, and contents in order to select publications relevant to the research aim. Following the skimming process, the ten documents that remained were analyzed, and the results are described in the next section.

RESULTS

A bibliographic search at the Scopus database resulted in 121 articles published by Elsevier Scopus between 2015 and 2021 however after a skimming process 10 significant articles were selected for this literature review, shown in Table 3.

Table 3 – Summary of documents analyzed

Document title	Authors	Year	Cited by	Source
Standardization and reproducibility in EV research: the support of a Quality Management System	Liguori, G.L. Kisslinger, A.	2021	4	Advances in Biomembranes and Lipid Self-Assembly
Fostering reproducibility, reusability, and technology transfer in health informatics	Hauschild, A.-C. Eick, L. Wienbeck, J. Heider, D.	2021	1	iScience
An empirical study: The multidimensionality of the quality management in determining university research laboratories performance	Outaki, M. Kerak, E.	2021	0	Accreditation and Quality Assurance
Improving the Quality of the Clinical Trial System through Comparative Study &	Kunga, T. Sano, M. Iwashita, M.	2019	0	Proceedings - 2019 IEEE/ACIS 4th International Conference on Big Data,

Requirements Modeling Approaches				Cloud Computing, and Data Science
An overview of Quality Management System implementation in a research laboratory	Molinéro-Demilly, V. Charki, A. Jeoffrion, C. Lyonnet, B. O'Brien, S. Martin, L.	2018	5	International Journal of Metrology and Quality Engineering
Quality Manual for Medical Research Companies Actualization According to GOST R ISO 9001-2015	Batcina, E.A. Artamonova, G.V. Guskova, M.F. Zaharova, L.M.	2018	1	Proceedings of the 2018 International Conference "Quality Management, Transport and Information Security, Information Technologies"
A Directional Comparative Analysis to Find Novel Approaches for Improving the Quality of the Clinical Trial System	Kunga, T. Sano, M. Iwashita, M.	2018	0	Proceedings - 2018 7th International Congress on Advanced Applied Informatics
Application and validation of DMAIC six sigma tool for enhancing customer satisfaction in a government R & D organization	Kansal, J. Singhal, S.	2017	6	International Journal for Quality Research
Establishment of a quality management system based on iso 9001 standard in a public service fungal culture collection	Simões, M.F. Dias, N. Santos, C. Lima, N.	2016	4	Microorganisms

ISO 9001:2008 implementation and impact on the university of Nairobi: A case study	Moturi, C. Mbithi, P.M.F.	2015	7	TQM Journal

The R&D organizations are heterogeneous; some are specialized towards one sector, others are interdisciplinary and have R&D activities pertaining to many sectors and different areas of knowledge. R&D organizations that focus on nuclear research, for example, and R&D organizations developed R&D activities for chemical industries for automotive industry and other research fields, such as Physical Sciences & Engineering, Life Sciences or Health Sciences. In this way, publications about quality issues could be found in different types of journals, conferences, and other publications.

The result shows that the theme quality management system based in ISO 9001 in R&D organizations found eco in different publications. Table 3 displays, for example, recent documents published in 2021 by three different sources: Accreditation and Quality Assurance; iScience and Advances in Biomembranes and Lipid Self-Assembly. Accreditation and Quality Assurance is a journal that publishes conceptual and practice-oriented articles on all aspects relevant to quality, transparency and reliability of measurement results in chemical and biological sciences (ACQUAL, 2022). iScience is a journal that has the goal to help fuel that type of interdisciplinary thinking and the primary criterion for publication is a significant contribution to a relevant field combined with robust results and underlying methodology (iScience, 2022). The aims of these publications are different and they referee how heterogeneous the R&D organizations are and how different publications recognized the relevance of the theme. It is not a subject only in quality management and it is a sign that there is a concern in the science community about the quality of R&D.

The interest in the theme could be measured by the number of citations and the number of documents published by year as shown in Figure 2. Seven of ten documents were cited at least once and five of ten documents at least four times. Six of ten documents were published in the last four years. The number and its distribution are aligned with the time frame explanation about the choice of the 2015 version of ISO 9001. Thus it’s possible that in the next years the number of publications related to ISO 9001 in R&D organizations increases. However, it depends if these organizations are interested to publish cases about implementation, motivations or other research questions in the quality management field.

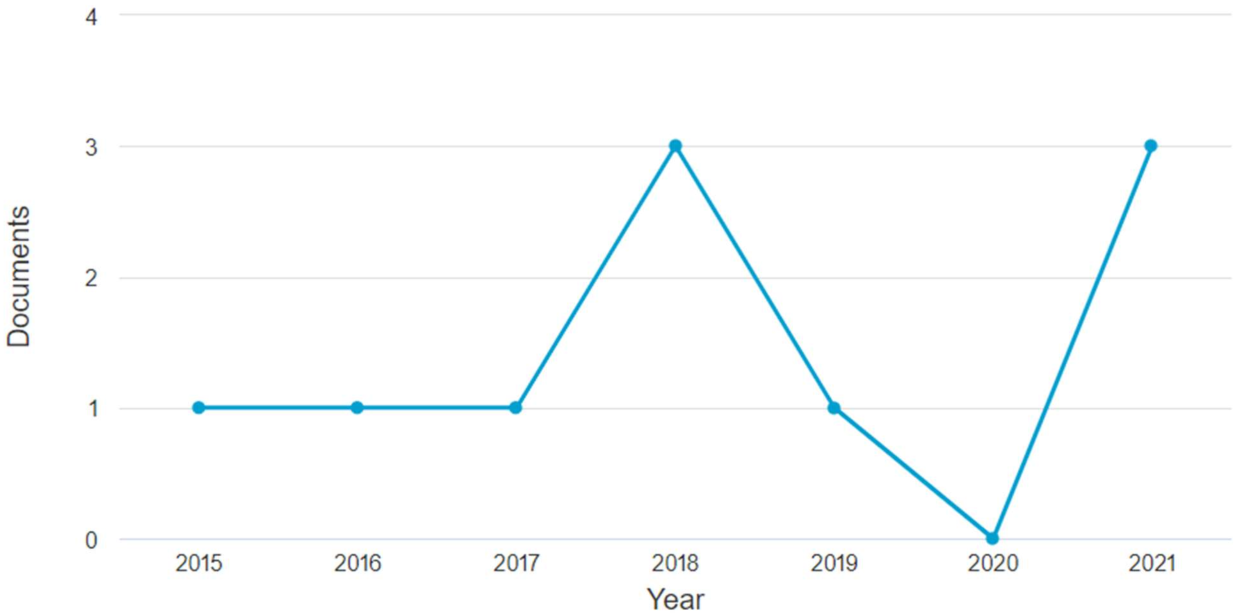

Figure 2 – Documents by year Source: Scopus

Figure 3 summarizes the documents published by country. The figure illustrates the query results which indicate that there is no leader by country in this research theme. But it is essential to note here the importance of Europe as appointed by others researchers results about ISO 9000 family diffusion as Gulier, I et al. (2002); Sampaio et al. (2009a), Sampaio et al. (2009b). Sampaio et al. (2009b) present ISO 900pc scores, which are considered issued certifications on a per capita basis in those countries that are listed in Figure 3: Japan, France, Germany, India, Italy, Portugal. Figure 3 shows that in more than fifty percent of the documents analyzed, the authors are from the same country as the issued certificates. Different evidence could be used to demonstrate the culture of quality management, such as obtaining ISO certification or published case studies that address ISO 9001 implementation, benefits, motivations, etc. The diffusion of the ISO 9001 standard has in fact been widely analyzed, but there is a bias in the geographical perspective used (Llach, et al., 2011). The authors present a sectorial view and the relevance to study the ISO 9001 phenomenon at a sectorial point of view.

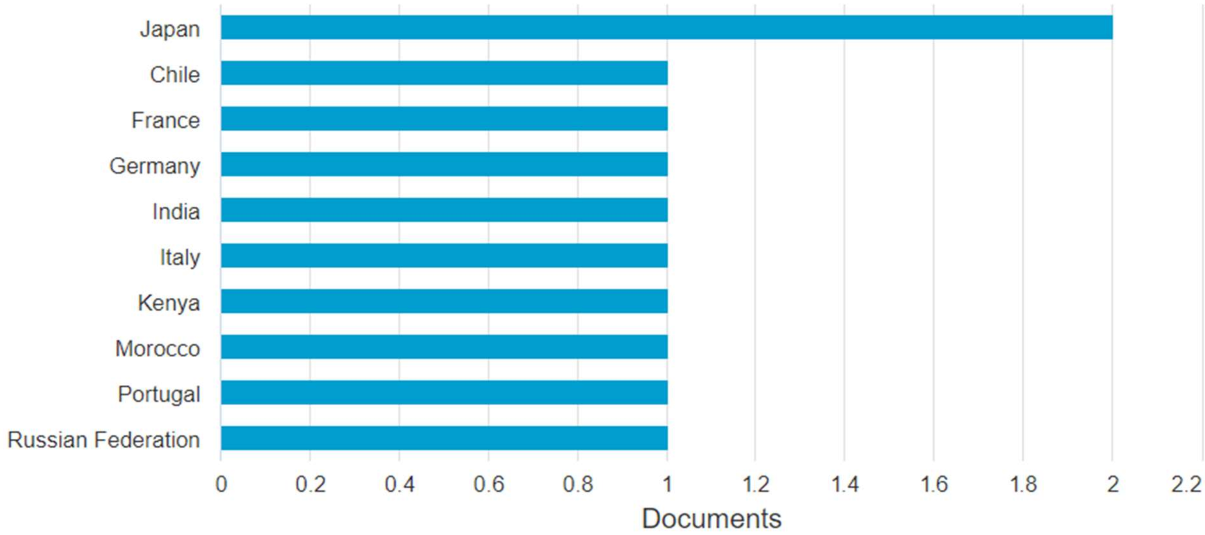

Figure 3 – Documents by country or territory Source: Scopus

As a result of this literature review four categories of research were sorted aimed to explore the theme quality management system based on ISO 9001 standard in R&D organizations showed in Table 5: survey about quality management in R&D organizations; relationship between clinical trials or medical research and quality management system; quality tools applied by R&D organizations; implementation or impact case study about ISO 9001 in R&D organizations.

Table 5 summary the essential points of the documents analyzed by categories

Authors	**Objectives**	**Findings/ conclusions**
Survey about Quality Management in R&D organizations		
Outaki, M. Kerak, E.	To measure the level of implementation of good quality management practices in research.	An explanatory model was established, based on a multiple linear regression, to identify the existence of an influence of good practices of quality management in research on the performance of Moroccan research laboratories.
Relationship between clinical trials or medical research and quality management system		
Batcina, E.A. Artamonova, G.V. Guskova, M.F. Zaharova, L.M.	To present the experience of scientific and medical institutions to update the quality Manual in accordance with the requirements of GOST R ISO 9001- 2015.	The creation and maintenance of this document makes it a useful tool for the effective operation of the organization and a modern weapon in the competition.

Authors	**Objectives**	**Findings/ conclusions**
Hauschild, A.-C. Eick, L. Wienbeck, J. Heider, D.	To establish an academia-tailored QMS for research organizations and units, which can significantly facilitate reproducibility and reusability of scientific software and speed up technology transfer in a controlled and predictable way.	This article proposes the first guidelines establishing an academia-tailored QMS for research organizations and units, which can significantly facilitate reproducibility and reusability of scientific software and speed up technology transfer in a controlled and predictable way.
Kunga, T. Sano, M. Iwashita, M.	To compare and analyze the correlation between the GCP Integrated Addendum- ICH E6 (R2) protocols and Quality Management System (QMS) ISO 9001:2015 requirements for improving the clinical trials system.	The analysis of the Integrated Addendum to ICH-E6 (R1), guidelines GCP-ICH-E6 (R2) with the Quality Management System ISO 9001: 2015 shows that the paragraphs in the good clinical practices (GCP) guideline have a connection with the paragraphs in the ISO 9001:2015. This work aims to find novel ways to improve the efficiency of the clinical trials system.
Kunga, T. Sano, M. Iwashita, M.	To study the detail analysis and comparison of the ISO 9001:2015 quality management methodology and GCP requirements to elaborate the methodological background in the context of this consistent integration for enhancing of the clinical trials system.	These domains of a directional comparison analysis and requirements modeling can be the preparatory step for developing novel approaches for information analysis to improve the quality of the clinical trial system. This work can assist in identifying the missing gaps and new approaches for future quality improvement in clinical trial systems.
Liguori, G.L. Kisslinger, A.	To develop and validate a QMS for innovative research projects.	The tools utilized and the models developed can be incorporated in a roadmap for the effective and efficient scientific management of innovative and multidisciplinary projects, specially focusing on EVs.
Quality tools applied by R&D organizations		
Kansal, J. Singhal, S.	To explore and validate DMAIC six sigma tool to enhance the customer satisfaction in an ISO 9001: 2008 certified government R&D organization.	The results indicate that Six Sigma tools can be applied to R&D organizations but with some modifications to the standard tools of Six Sigma.

Authors	Objectives	Findings/ conclusions
Molinéro-Demilly, V. Charki, A. Jeoffrion, C. Lyonnet, B. O'Brien, S. Martin, L.	To show the advantages of implementing a Quality Management System (QMS) in a research laboratory in order to improve the management of risks specific to research programmes and to increase the reliability of results.	This paper clearly illustrates the effectiveness of the actions considered by looking at the 7M method and giving practical examples which involve both the organization and the activities of the laboratory.
Implementation or impact case study about ISO		
Moturi, C. Mbithi, P.M.F.	To present the experience and impact of implementing the ISO 9001: 2008 Standard at the University of Nairobi.	The paper describes the implementation and subsequent impact of the ISO 9001 Standard in a Kenyan University and that the universities must adopt a quality management approach beyond certification and compliance to requirements in order to achieve long-term sustainable success.
Simões, M.F. Dias, N. Santos, C. Lima, N.	To report a detailed description of all the steps taken for the QMS implementation at Micoteca da Universidade do Minho (MUM).	After achieving ISO 9001 certification at MUM, it has been easier to detect and correct gaps and flaws in all methods and procedures, and trace all essential items regarding the final products which lead to substantially upgraded quality of services and products.

Aside from the categories created, it is possible to consider internal and external motivations as presented by Sampaio et al. (2009b). Internal motivations according to the authors are related to the goal of achieving organizational improvement. External motivations according to the authors are related to promotional and marketing issues, customer pressures, improvement of market share, etc.

Internal motivation appears in documents analyzed in order for R&D organizations to have a quality management system based on ISO 9001 standard. There is a consensual opinion that ISO 9001 benefits are related to company certification motivations, i.e. when companies become certified based on internal motivations the derived benefits are fulfilled on a more global dimension (Sampaio, Saraiva at al., 2009b). The analysis of 10 documents is not enough to suggest that internal motivations are dominant or not to achieve an ISO 9001 certified scope. This internal motivation could be more explored in the R&D organization context.

External motivation appears in documents analyzed in order for R&D organizations to have a quality management system based on ISO 9001 standard. It seems to be a major common element in documents analyzed: a stakeholder pressure in order to have a quality management system based on

ISO 9001 standard. Especially in the “relationship between clinical trials or medical research and quality management system” category. One of the main motivations mentioned by companies to achieve ISO 9001 certification is “customer pressure” is (Sampaio et al., 2009b). Part of certifications can be explained by pressure exerted by downstream customers through global supply chains on upstream firms in other countries (Corbett, 2006). The analysis of 10 documents is not enough to suggest that most of R&D organizations face or doesn't face a stakeholder pressure to achieve an ISO 9001 certified scope. This external motivation or supply chain requirement could be more explored in the R&D organization context.

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CONCLUSIONS

This literature review shows that there is still a wide room for future works concerning quality management in R&D organizations. The work sorted four categories of research inside our theme. This is significant because it could help to explore each category to better understand quality management in R&D organizations.

The result of the query showed there are not many case studies published to report the implementation or benefits of ISO 9001 in R&D organizations. But this work sorted four categories of works and it appears a signal different concern about quality in R&D organizations. Thus, these findings open a new opportunity window for further research about standards, tools and methods to improve the quality of R&D activities in R&D organizations.

It’s important to highlight that the results are related to ISO 9001 standard. Thus other standards like ISO/IEC 17025, ISO/IEC 17065, ISO/IEC 17024 and ISO/IEC 17043, for example, could help to understand quality management in R&D organizations. These categories were related to the result of an analysis of ten documents based on the ISO 9001 standard which suggests a new research field but requires new research to further investigate.

The use of the keywords ISO 9001 and 9001 and a time frame filter that was used in this work query could restrict the results. This time frame was selected based on the year of the current version of ISO 9001 standard as already explained. Beyond the study of quality standards in R&D organizations are quality management in R&D organizations. It is possible that R&D organizations have adopted other standards or models.

A next step could be the study of the quality management systems employed by R&D organizations. Perhaps a number of ISO 9001 R&D organizations have not been certified to the new ISO 9001 version. Besides that, there are not many publications about quality management systems in R&D organizations. In this case, it difficult the diffusion process thus diffusion is spread through mimicking the practices of others (Llach et al., 2011).

Sampaio et al. (2009b) suggest an interesting question about what are the typical companies' profiles that achieve ISO 9001 certifications, considering that they follow external or internal motivations. The proposed question could be adapted to R&D organizations' motivations to adopt ISO 9001 or another standard and even other quality management model in future studies.

REFERENCES

ACQUAL (2022) "Aims and scope" ", available at: https://www.springer.com/journal/769/aims-and-scope (accessed 12 Mai 2022).

Batcina, E A, Artamonova, G V, Guskova, M F and Zaharova, L M (2018) "Quality Manual for Medical Research Companies Actualization According to GOST R ISO 9001-2015". In 2018 IEEE International Conference "Quality Management, Transport and Information Security, Information Technologies"(IT&QM&IS) (pp. 583-586). IEEE.

Corbett, C J (2006) "Global diffusion of ISO 9000 certification through supply chains". Manufacturing & Service Operations Management, 8(4), pp.330-350.

Di Luozzo, S, Varisco, M and Schiraldi, M M (2020) "The diffusion of international standards on managerial practices". International Journal of Engineering Business Management, 12, p.1847979020921611.

Guler, I, Guillén, M F and Macpherson, J M (2002) "Global competition, institutions, and the diffusion of organizational practices: The international spread of ISO 9000 quality certificates". Administrative science quarterly, 47(2), pp.207-232.

Hauschild A, Wienbeck L and Heider D (2021) "Fostering reproducibility, reusability, and technology transfer in health informatics". iScience, Vol. 24, Issue 7, 102803, pp. 1-10

iSCIENCE (2022) "Aims and scope" ", available at: https://www.cell.com/iscience/aims (accessed 12 Mai 2022).

ISO, 2021. ISO Survey. Available at: http://www.iso.org/iso/iso-survey [Accessed April 04 , 2022].

ISO, 2022. Available at https://www.iso.org/conformity-assessment.html [Accessed April 08 , 2022].

Kansal, J and Singhal, S (2017) Application and validation of dmaic six sigma tool for enhancing customer satisfaction in a government r&d organization. International Journal for Quality Research, 11(4), p.931.

Kunga T, Sano M and Iwashita M (2019) "Improving the Quality of the Clinical Trial System through Comparative Study & Requirements Modeling Approaches". IEEE International Conference on Big Data, Cloud Computing, Data Science & Engineering (BCD), pp. 5-10.

Liguori, G.L. and Kisslinger, A (2021) “Standardization and reproducibility in EV research: the support of a Quality Management System”. In Advances in Biomembranes and Lipid Self-Assembly (Vol. 33, pp. 175-206). Academic Press.

Llach, J, Marimon, F and Bernardo, M (2011). “ISO 9001 diffusion analysis according to activity sectors”. Industrial Management & Data Systems.

Molinéro-Demilly, V., Charki, A., Jeoffrion, C., Lyonnet, B., O'Brien, S. and Martin, L., 2018. An overview of Quality Management System implementation in a research laboratory. International Journal of Metrology and Quality Engineering, 9, p.2.

Moturi, C and Mbithi, P M, (2015) “ISO 9001: 2008 implementation and impact on the University of Nairobi: A case study”. The TQM journal.

OECD (2015) “Frascati Manual 2015: Guidelines for Collecting and Reporting Data on Research and Experimental Development, The Measurement of Scientific, Technological and Innovation Activities”, OECD Publishing, Paris, Available: https://www.oecd-ilibrary.org/science-and-technology/frascati-manual-2015_9789264239012-en [Accessed september 04 , 2020].

Outaki, M and Kerak, E. (2021) “An empirical study: The multidimensionality of the quality management in determining university research laboratories performance”. Accreditation and Quality Assurance, 26(2), pp.91-97.

Pinto C, Romero F (2020) “The Relationship between Quality Management and Innovation” Proceedings of the 4th ICQEM Conference, University of Minho, Portugal, 2020, pp.259-274

Psomas, E L and Fotopoulos, C V (2009). “A meta analysis of ISO 9001: 2000 research–findings and future research proposals”. International Journal of Quality and Service Sciences.

Sampaio, P Saraiva, P and Guimarães Rodrigues, A (2009a) “An analysis of ISO 9000 data in the world and the European Union”. Total Quality Management, 20(12), pp.1303-1320.

Sampaio, P, Saraiva, P and Rodrigues, AG, (2009b) “ISO 9001 certification research: questions, answers and approaches”. International journal of quality & reliability management.

Sené, M, Gilmore, I, and Janssen, J T (2017) “Metrology is key to reproducing results”. Nature, 547(7664), 397-399.

Simões, M F, Dias, N, Santos, C and Lima, N (2016) “Establishment of a quality management system based on ISO 9001 standard in a public service fungal culture collection”. Microorganisms, 4(2), p.21.

Troian A, Gomes M C (2020) “A bibliometric analysis on the use of the multicriteria approach to the water resource management” Gestão & Produção, 27(2), e4761

Vermaercke, P (2000) “Sense and nonsense of quality assurance in an R&D environment”. Accreditation and quality assurance, 5(1), pp.11-15.

Vré, M D (2000). “The scope and limitations of a QA system in research”. Accreditation and quality assurance, 5(1), pp.3-10.

Exploratory Spatial Data Analysis of ISO 9001 certification trends and innovation performance in South America

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ABSTRACT

Purpose – The present paper aims to present an Exploratory Spatial Data Analysis (ESDA) of ISO 9001 certification trends and innovation performance in order to identify geographic patterns and spatial autocorrelation between performance innovation and annual growth rate of ISO 9001 certificates in South America.

Design/methodology/approach – Using secondary data regarding the number of ISO 9001 valid certificates and innovation indexes, our methodological procedure combines descriptive analysis and ESDA to verify spatial autocorrelation hypotheses and spill-over effects across countries.

Findings – The results reveal spatial patterns regarding the ISO 9000 certification trends in South American countries. The ESDA results call attention to the association of annual growth rate of ISO 9001 certificates with gross capital formation, expenditure on education, and high-tech manufacturing. In addition, the study points to spatial clusters regarding these measures.

Research limitations/implications- As the study relies on South American country data, future research should explore spatial patterns and spill-over effects using samples from other regions or continents.

Practical implications- This study discusses the association between ISO 9001 Quality Management Systems (QMS) and innovation performance from a geographic perspective. Moreover, the findings indicate associations between the demand for ISO 9001 certificates and innovation performance indicators.

Originality/value – This paper presents an exploratory study regarding the effect of innovation performance and ISO 9001 QMS certification in South American countries using ESDA techniques.

Keywords: ISO 9001, Quality Management, Exploratory Spatial Data Analysis.

Paper type: Research paper.

INTRODUCTION

Since 1987 many organizations have sought the certification of Quality Management Systems (QMS) through ISO 9000 standards to facilitate the exchange of goods and services among different countries by employing a common set of quality standards (Sharifi et al., 1999). According to a survey carried out by the International Organization of Standardization (ISO, 2022), by the end of 2020, there were over 908,000 certificates issued worldwide, distributed in 195 countries. Currently, South America is the Top 3 global region in the number of ISO 9001 valid certificates.

Due to the globalization of the economy, companies are looking for international standards to facilitate trade and reduce barriers linked to national standards (Boiral, 2003). Implementing ISO 9001 requirements is suitable for both service organizations and manufacturing processes. However, the most expressive sectors in relation to the number of ISO 9001 certificates issued in 2020, according to the ISO survey (ISO, 2022), cover basic metal and fabricated metal products (10%), electrical and optical equipment (8%), retail trade, repairs of vehicles, and household goods (8%), construction (7%), machinery and equipment (6%), and other services (5%).

Current literature on the topic provides empirical evidence regarding the positive impact of ISO 9000 QMS on operational excellence and financial performance (Aarts and Vos, 2001; Corbett et al., 2005; Lo et al., 2009; O'Neill et al., 2016). Nevertheless, quality and innovation are two complementary issues to raise organizational performance (El Manzani et al., 2019). Research addressing the impact of ISO 9000 QMS on performance innovation has generated controversial results. On the one hand, some studies suggest that implementing the ISO 9000 may have a positive effect on innovation (Prajogo and Sohal, 2004, Anttila and Jussila, 2017; Shi et al., 2019). Otherwise, other studies found that ISO 9000 certification can reduce flexibility and stifles innovation performance (Benner and Tushman, 2002; Magd and Curry, 2003; Terziovski and Guerrero, 2014).

Previous research on the topic suggests that the level of quality management practices in a given country could be influenced by the practices adopted by companies in neighboring countries (Kopstein and Reilly, 2000). With respect to ISO 9000 certification, studies indicate that the adoption of this QMS in a country could be motivated if its export markets have many certified companies (Prakash and Potoski, 2006). Furthermore, the ISO 9000 adoption could be encouraged if a country's structurally equivalent competitor has a high number of certifications (Cao and Prakash, 2011). Concerning innovation performance, there seems to be a positive relationship between the number of certified countries and the number of countries that adopt innovative practices (Sampaio et al., 2009). The region in which a company operates can influence efforts directed towards innovation performance and QMS certification (Manders et al., 2016).

It is important to highlight that the relationships between ISO 9000 and business performance are complex and underdeveloped, mainly when the research encompasses systematic measurements and multi-organizational comparisons (Simmons and White, 1999). Although numerous papers about 9000 QMS have been published in recent decades, there is little research applying spatial statistics techniques through georeferenced data and survey data. Most of these papers tended to be descriptive, with little attention devoted to testing empirical hypotheses. In this context, Explorative Spatial Data Analysis (ESDA) represents an effective method of testing the existence of spatial autocorrelation processes (Kopczewska and Kubara, 2020).

This study aims to present an ESDA of ISO 9001 certification trends and innovation performance to identify geographic patterns and spatial autocorrelation between performance innovation and annual growth rate of ISO 9001 certificates in South American countries. The paper is organized as follows. The following section briefly reviews the literature on ISO 9000 QMS and innovation performance. Afterward, the methodology for collecting data and carrying out the ESDA is described. Next, a discussion of the results is presented. Finally, the concluding section addresses the study's limitations and future research directions.

LITERATURE REVIEW

The International Organization for Standardization (ISO) is a worldwide organization established in 1947 in Geneva to develop common international standards in many areas (Sroufe and Curkovic, 2008). The first series of ISO 9000 standards were released in 1987 by ISO to promote global trade and quality improvement (Lee and Palmer, 1999). The objectives of ISO 9001 certification programs are twofold. Internally, it seeks to improve an organization's quality management practices; Externally, it demonstrates a commitment to quality assurance to external stakeholders (Cao and Prakash, 2011). In addition, the ISO 9000 standards can facilitate the exchange of goods and services through a common set of quality standards (Sharifi et al., 1999).

Despite the broad theoretical discussion on the benefits of ISO 9000 QMS, some criticisms are pointed out in the literature regarding excessive documentation (Aarts and Vos, 2001), implementations motivated by external pressure, competitor’s certification, and advertising needs (Gotzamani and Tsiotras, 2002; Manders et al., 2016) as well as the ability to improve quality (internal and external) and customer satisfaction (Gotzamani and Tsiotras, 2002). The main barriers to QMS implementation include infrastructure and low investment (Ngai and Cheng, 1997; Al-Khalifa and Aspinwall, 2000), cost of registration (Taylor, 1995), resistance to change, and lack of management commitment (Bounabri et al., 2018). Furthermore, there seems to be a saturation point between 1.2 to 1.6 ISO 9000 certificates per 1000 habitants (Saraiva and Duarte, 2003).

The original ISO 9000 standards published in 1987 underwent a major revision in 1994, requiring that organizations prove a verifiable quality system to ensure that it consistently produced what it said it would produce (Sroufe and Curkovic, 2008). Since then, ISO had reviewed its ISO 9001 standard in 2000, combining ISO 9001, 9002, and 9003 into one standard, while ISO 9001:2008 was basically the same as the previous version (Manders et al., 2016). The current standard (ISO 9001:2015) attempts to provide changes with reference to (Fonseca, 2015): (i) the adoption of a common high-level structure for all ISO management system standards; (ii) concept change from "management responsibility" to "leadership"; (iii) requirement addressing the “context of the organization”; (iv) inclusion of risk-based-thinking; and (v) less emphasis on prescriptive requirements and documentation.

Part of the literature considers that QMS and innovation are not mutually exclusive strategies. It is worth noting that ISO 9000 QMS tends to be more associated with process innovation than product innovation performance (Marash and Marquardt, 1994). Different indexes can be adopted to measure the innovation levels of an organization or country. Such indexes are based on indicators relating to the degree of innovation adoption, acquisition of knowledge, and continuous innovation (Läpple et al., 2015). The Innovation Union Scoreboard, the World Economic Forum (WEF), and the Global Innovation Index (GII) stand out among these indexes. Such measures can become a source of meaningful insight into countries’ levels of innovation performance (Sohn et al., 2016).

Our study addresses four GII indexes: (i) Gross Capital Formation; (ii) Expenditure on Education; (iii) Labor Productivity Grow; and (iv) High-tech Manufacturing. Woolthuis et al., (2005) found that failure between QMS and innovation may be due to infrastructural factors, including low investment in facilities. On the other hand, the level of investment in education may be associated with QMS implementation. According to Lopéz-Mielgo et al., (2008), a high proportion of trained employees (including technicians, engineers, and managers) encourages process innovation and maximum performance from the quality management practices. Simao and Franco (2018) indicated that implementing ISO 9000 QMS can improve organizational innovation when the knowledge transfer is continuously improved.

Manders et al., (2016) argue that the focus on productivity and efficiency from an internal quality perspective can increase innovation performance. Furthermore, In the age of Industry 4.0, companies will be able to apply for ISO 9000 QMS to facilitate the standardization of processes and implement digital technologies. From this perspective, Escanciano et al., (2002) argue that companies with higher technological levels and active innovation strategies are more satisfied with the benefits of the Total Quality Management approach. According to Manders et al., (2016), different levels of technology influence the adoption of ISO 9000 QMS and, consequently, innovation performance.

DATA COLLECTION AND METHODOLOGY

The ESDA was carried out using secondary data obtained from two sources. To access information on the number of certificates issued in the continents and countries, we collected the full survey data available at https://www.iso.org/the-iso-survey.html in an Microsoft Excel spreadsheet. Next, we extracted four innovation indexes from the countries of South America in the *Global Innovation Indexes 2021* report (WIPO, 2021), as highlighted in Table 1. Such indexes were selected according to the innovation features discussed in the literature review. Then, we combine this data in a single spreadsheet to compile the information needed for the research.

Table 1 – Innovation performance indexes.

Indexes	Description
 Gross Capital Formation, % GPD	Gross Capital Formation (GCF) is expressed as the ratio of total investment in current local currency to GDP. It measures the total value of the gross fixed capital formation and changes in inventories and acquisitions less disposals of valuables for a unit or sector, based on the System of National Accounts.
 Expenditure on Education, % GPD	Expenditure on Education (EoE) is based on the Total (local, regional and central) government expenditure on education, expressed as a percentage of GDP. It includes expenditure funded by transfers from international sources to government.
 Labor Productivity Growth, %	Labor Productivity Growth (LPG) is the rate of GDP per person employed based on the average of three most recent available years (2018, 2019, 2020). Growth of GDP per person engaged provides a measure of labor productivity (defined as output per unit of labor input). GDP per person employed is GDP divided by total employment in the economy.
 High-tech Manufacturing, %	High-Tech and Medium-High-Tech Manufacturing (HTM) is a percentage of total manufacturing output, on the basis of the OECD classification of Technology Intensity Definition, according to the International Standard Industrial Classification (ISIC).

Source: WIPO (2021).

We carried out a descriptive analysis to identify the distribution and evolution of certificates issued across South American countries. Next, to perform the ESDA, we defined the Annual Growth Rate of Number of ISO 9001 Certificates (AGRNC) as a dependent variable. This measure was calculated as follows:

$$AGRNC = \left[\left(\frac{Number\ of\ certificates\ in\ the\ last\ year}{Number\ of\ certificates\ in\ the\ first\ year}\right)^{\frac{1}{n}} - 1\right] \tag{1}$$

Where n is the number of years within the period 2000-2020. The four indexes presented in Table 1 were defined as explanatory variables. All variables were then standardized. In the context of ESDA, autocorrelation is the tendency of z_i values of nearby polygons (Brunsdon and Comber, 2014).

Otherwise, spatial autocorrelation means that geographically close observations are more similar to each other than distant ones (Kopczewska and Kubara, 2020). Input data (spreadsheets and shapefile data) were processed using R software.

To perform the ESDA, we apply global and local autocorrelation measures. The global measures are a single-digit indicator representing the general similarity of regions and can be measured by Global *Moran's* I, ranging from -1 to 1. When the value of *Moran 's* I is positive and closer to 1, there is a clustering trend in the spatial distribution. In the other hand, when the value of *Moran's* I is negative and closer to -1, there are more discrete trends in the spatial distribution (Li et al., 2018). The *Moran's* I coefficient can be written as follows:

$$I = \frac{n}{\Sigma_i \Sigma_j w_{ij}} \frac{\Sigma_i \Sigma_j w_{ij}(z_i - \overline{z})(z_j - \overline{z})}{\Sigma_i (z_i - \overline{z})^2} \tag{2}$$

Where w_{ij} is the (i, j)th element of a weights matrix **W**, specifying the degree of dependency between polygons i and j. As explained by Brunsdon and Comber (2014), if **W** is standardized so that its rows sum to 1, the Equation (2) can be simplified as follows:

$$I = \frac{\Sigma_i \Sigma_j w_{ij} q_i q_j}{\Sigma_i q_i^2} \tag{3}$$

Where $q_i = z_i - \bar{z}$; that is, q_i is z_i around the mean value of z. However, if the vector of q_i values is written as q, the Equation (3) can be simplified as a vector-matrix form as follows:

$$I = \frac{q^T w q}{q^T q} \tag{4}$$

Although the Global *Moran's* I can be understood as a linear correlation coefficient, i.e., global autocorrelation, the Local *Moran's I* captures if a particular region is surrounding by neighboring regions with similar values. In this context, a spatial spill-over effect is evidence that the degree of agglomeration in a region depends on some influencing factors from another (Li et al., 2018). The Local *Moran's* I was used to identify Local Indicator of Spatial Association (LISA) and spill-over effect. Specifically, the Local *Moran's* I can be stated as follows:

$$LI = \frac{(x_i - \bar{x}) \sum_{i=1}^{n} w_{ij}(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2 / n} \tag{5}$$

Where the w_{ij} represents the spatial weight matrix. The spatial agglomeration models are divided into a High-High aggregation model (HH), High-Low aggregation model (HL), Low-High aggregation model (LH), and Low-Low aggregation model (LL).

RESULTS

Descriptive Analysis

According to the ISO Survey (ISO, 2020), the Top 10 countries with more ISO 9001 valid certificates includes China (324,621), followed by Italy (91,493), Germany (49.349), Japan (32,287), India (32.232), Spain (29,814), UK (25,995), France (21,880), USA (20,919), and Brazil (17,503). Figure 1 depicts a world map highlighting the Top 3 countries with more ISO 9001 certificates for each region of the globe. The figure also highlights South America, which currently holds the third position in the continental ranking with 41,575 ISO 9001 valid certificates issued.

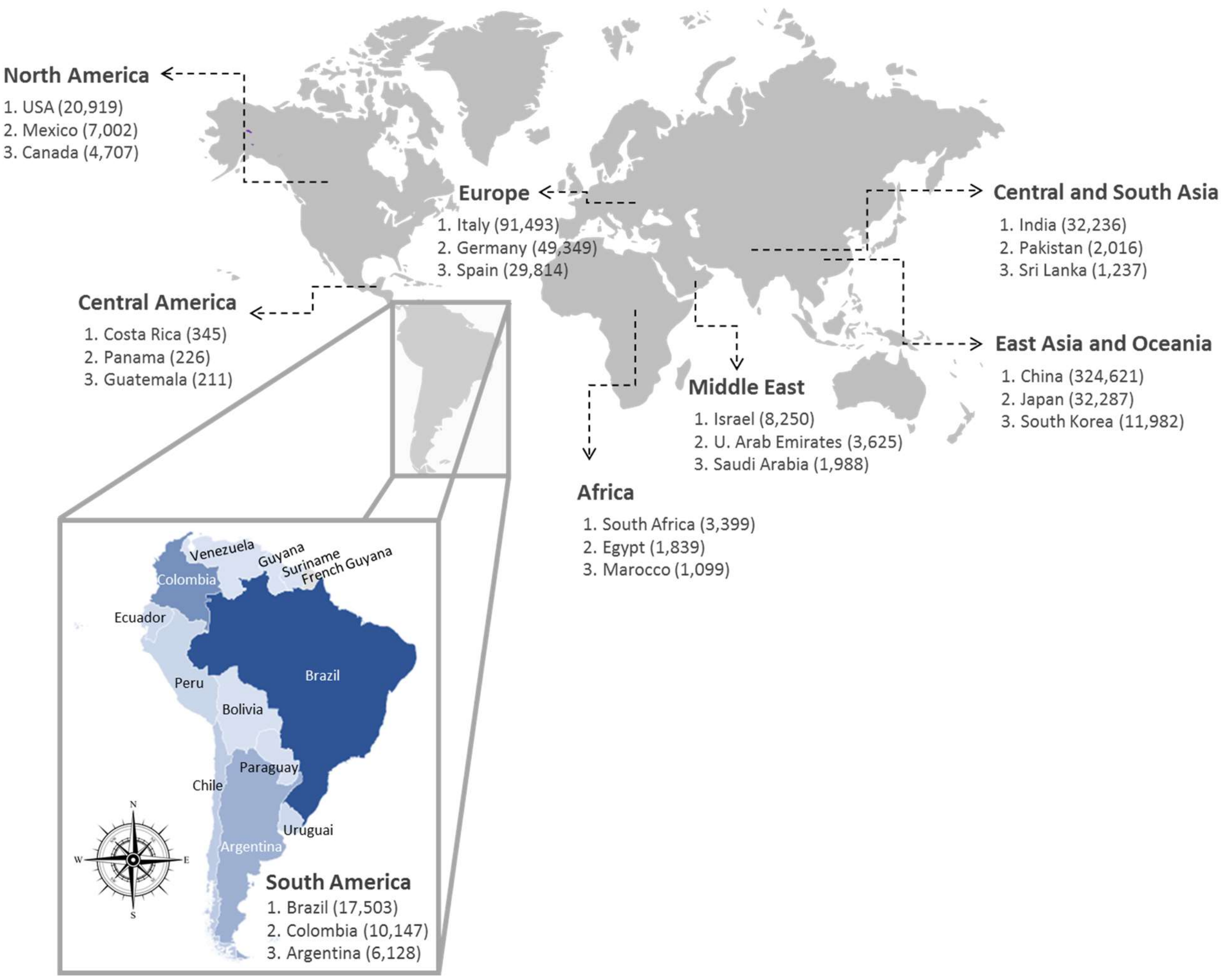

Figure 1 – Top 3 countries with more ISO 9001 valid certificates worldwide.

As seen in Figure 1, Colombia holds the second position in the ISO 9001 South America ranking with 10,147 certificates, followed by Argentina (6,128 certificates). However, the order of countries with the highest number of certificates has changed over the period based on revisions of the ISO 9000 standards. The position variation in this ranking throughout the series is observed for Argentina, Colombia, Chile, and Uruguay. Figure 2 shows the Hot Spot, Cold Spot maps based on the number of certificates issued in 1993, 2000, 2010, and 2020.

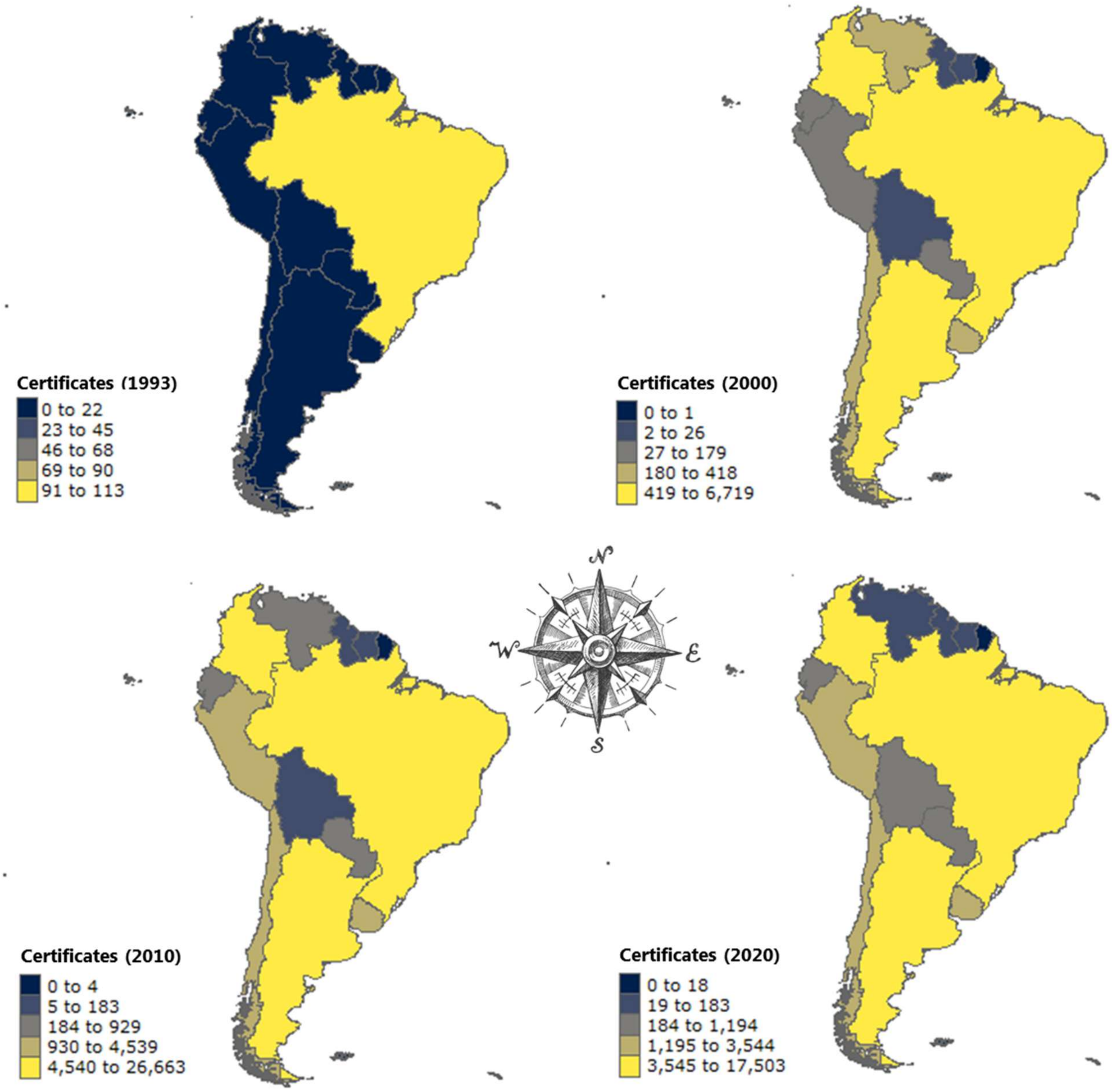

Figure 2 – Hot Spot, Cold Spot maps referring to the number of ISO 9001 certificates

When analyzing the evolution of Hot Spot, Cold Spot maps stratified into four periods, a pattern is observed in the number of certifications between countries. In 1993, Brazil covered 82% of all ISO 9000 certificates issued in South America. However, after the second revision of the standard (ISO 9001:2000), this percentage dropped to 64%. Currently, Brazil represents 42% of the total number of ISO 9000 certificates on the continent. While Argentina ensured the Top 2 position from 2000 to 2010 with an average of 4,837 certificates issued in the period (3% higher than Colombia), the Top 2 position from 2010 to 2020 went to Colombia, whose average number of certificates evolved to 11,433 (78% higher than Argentina). In addition to the Argentina-Brazil-Colombia triad, there is a maintenance of the growth rate in the number of certificates held in Chile, Peru, and Uruguay, placing these countries in an intermediate range. Meanwhile, there is a decrease in certificates issued for northern countries (Guyana, Suriname, and Venezuela).

Table 2 shows the descriptive statistics relating to the number of ISO 9001 certificates observed in nine countries of South America. Due to the absence of data in the GII, some countries were not included in this analysis (*e.g.*, Suriname, Venezuela, etc.). While Brazil, Colombia and Argentina stand out in terms of the number of certificates, other countries like Ecuador, Paraguay, Bolivia, Chile, and Peru, along with Colombia, present a better performance in AGRNC. The GCF, EoE, LPG, and HTM indexes reveal each country's innovation performance in different dimensions. As explained previously, these indexes were used as predictor variables in the ESDA.

Table 2 – Descriptive statistics and indexes of the countries in the dataset.

Country	AGRNC	Number of Certificates (2000-2020)			GCF	EoE	LPG	HTM
		Minimum	Maximum	Mean				
Argentina	0.0553	1,790	8,812	5,594	17.3	4.9	-2.2	28.1
Bolivia	0.1216	20	242	160	16	-	0,5	7,7
Brazil	0.0466	4,012	28,325	15,295	14,7	6,3	1,3	36,3
Chile	0.1270	229	5,283	2,985	22,1	5,4	1,4	23,9
Colombia	0.1428	614	14,531	7,896	19,7	4,5	3,6	20
Ecuador	0.1312	29	1,369	744	22,4	5	0,2	13,3
Paraguay	0.1359	30	437	204	24,8	3,4	-0,7	15
Peru	0.1235	141	1,737	839	19,2	3,8	3,3	13,6
Uruguay	0.0774	200	1,338	775	16,3	5	2,1	15,3

AGRNC (Annual Growth Rate in the Number of Certificates 2000-2020); GCF (Gross Capital Formation, %); EoE (Expenditure on Education, %); LPG (Labor Productivity Growth, %); HTM (High-Tech Manufacturing, %).

Exploratory Spatial Data Analysis

In order to capture the general spatial trends in the region selected in this study, we proceed with tests of significance based on *Moran*'s I. According to the arguments presented in this paper, proximity between countries using social distance (GCF, EoE, LPG, and HTM) may indicate autocorrelation (positive or negative) with the AGRNC. Hence, the pair of hypotheses were formulated as follows:

> *H_0: There is spatial randomness between innovation performance (based on a specific index) and the annual growth rate of ISO 9001 certifications across countries.*
>
> *Ha: There is no spatial randomness between innovation performance (based on a specific index) and the annual growth rate of ISO 9001 certifications across countries.*

An examination of the *p-values* and Global *Morans' I* shown in Table 3, indicates spatial non-randomness for the hypotheses related to GCF (H_1), EoE (H_2), and HTM (H_3) at a significance level of 5% (α = 0,05). Such results show that gross capital formation, expenditure on education, and the proportion of high-tech manufacturing have autocorrelation with the annual growth rate of ISO 9001 certificates issued in South America. On the other hand, there is no statistical evidence that the labor productivity grow is autocorrelated with AGRNC (p-value > 0.05).

Table 3 – Results of Global *Moran's* I test.

Hypothesis	*Moran's I*	Expectation	Variance	*p-value*
H_1 - Spatial randomness between GCF and AGRNC	0.1005	-0.2000	0.0238	0.0258
H_2 - Spatial randomness between EoE and AGRNC	0.0047	-0.2500	0.0107	0.0069
H_3 - Spatial randomness between LPG and AGRNC	-0.1999	-0.2000	0.0173	0.4997
H_4 - Spatial randomness between HTM and AGRNC	0.2076	-0.2000	0.0127	0.0001

Figure 3 displays the Global *Moran's I* scatterplots for each hypothesis test. As seen in Figure 3(a), the spatial autocorrelation between GCF and AGRNC (spatially lagged) suggests the high GCF corresponds to the high AGRNC in Peru, Chile and Ecuador, while the low GCF corresponds to the low AGRNC in Brazil, Uruguay and Argentina. This finding provides support for Hypothesis 1a. The spatial autocorrelation between EoE and AGRNC illustrated in Figure 3(b), indicates that the high EoE is statistically related to the increase of AGRNC in Chile and Uruguay, while the low EoE reflects a minor AGRNC in Colombia and Paraguay. Therefore, Hypothesis 2a is also supported.

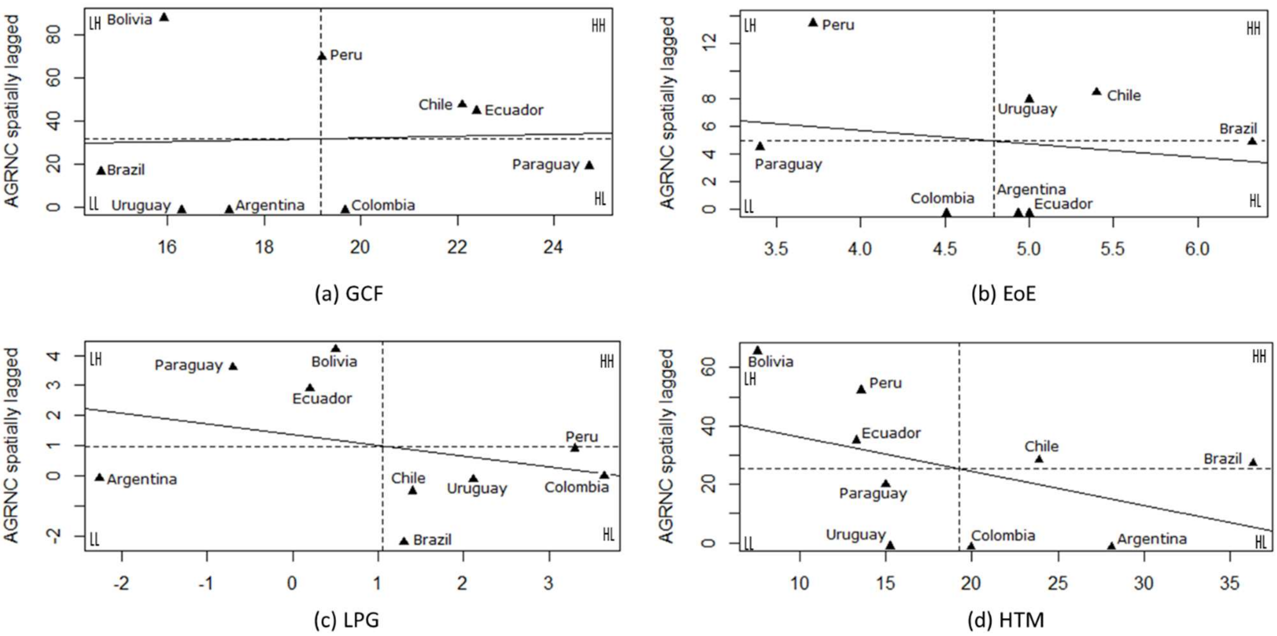

Figure 3 – Global *Moran's I* scatterplots

As seen in Figure 3(c), Hypothesis 3a is supported, revealing the absence of countries in the HH quadrant and only one country (Argentina) positioned in the LL quadrant. The other countries allocated in the HL and LH quadrants can be interpreted as spatial outliers. Finally, Figure 3(d) supports Hypothesis 4a highlighting Brazil and Chile as HH and Paraguay and Uruguay as LL. As explained previously, Local *Moran*'s I measure whether a country is affected by neighboring regions with similar or different values regarding the random geographic distribution of these values. Negative values can indicate that relatively low values surround a country in neighboring countries (in this case, using social distances), while positive values suggest that relatively high values surround a country. Since the presentation of Local *Moran's* I statistics in tables can confuse the researcher, it is recommended to build LISA significance maps (Almeida, 2012).

Figure 4 presents the Local *Moran's* I maps highlighting the countries with significant Local *Moran's* I values through different colors, according to the positioning in the HH, HL, LH, and LL quadrants. Thus, blank countries are characterized as not statistically significant. In other words, Local *Moran*'s I map can indicate significant clusters (Piatkowska et al., 2018). Figure 4(a) reveals that Chile presents high AGRNC associated with high GCF (HH) next to the cluster formed by Colombia and Peru, whose performance is classified as HL. In the opposite direction, another cluster is formed by Argentina, Bolivia and Uruguay, whose correction between AGRNC and GCF is negative (LL). Therefore, the identification of these two clusters may indicate the spill-over effect.

Looking at Figure 4(b), it is noticed that the association between EoE and AGRNC is more significant for Colombia (HH) as well as for the cluster grouping Argentina and Uruguay (HL). Although the alternative hypothesis for the association between LPG and AGRNC was rejected based on the Global *Moran's* I, a significant association between increased productivity and AGRNC (HH) for Colombia and Uruguay suggests a spill-over effect highlighted in Figure 4(c). Finally, in addition to the LL position observed for Uruguay, Figure 4(d) shows the last cluster connecting Argentina and Colombia in the HL quadrant, indicating that the number of ISO 9001 certificates in these countries is not associated with the number of high-tech companies.

CONCLUSION

In this paper we have presented the results of an ESDA in order to identify geographic patterns and spatial autocorrelation between performance innovation indexes and annual growth rate of ISO 9001 certificates in South American countries. Our analysis was performed using secondary data. First, we sought to identify spatial patterns regarding to ISO 9000 QMS in South American countries using a descriptive analysis approach. Although Brazil has held the leading position in the number of ISO 9001 valid certificates over time, Argentina, Colombia, Chile, and Uruguay have shifted between the Top 5 positions.

Next, we carried out an ESDA to explore general spatial trends and test hypotheses about spatial randomness between innovation performance indexes and the annual growth rate of ISO 9001 certifications across countries. The results of ESDA call attention to the autocorrelation of AGRNC with GCF, EoE, and HTM indexes. Using the Global *Moran's* I and Local *Moran's* I, we captured non-random patterns across countries.

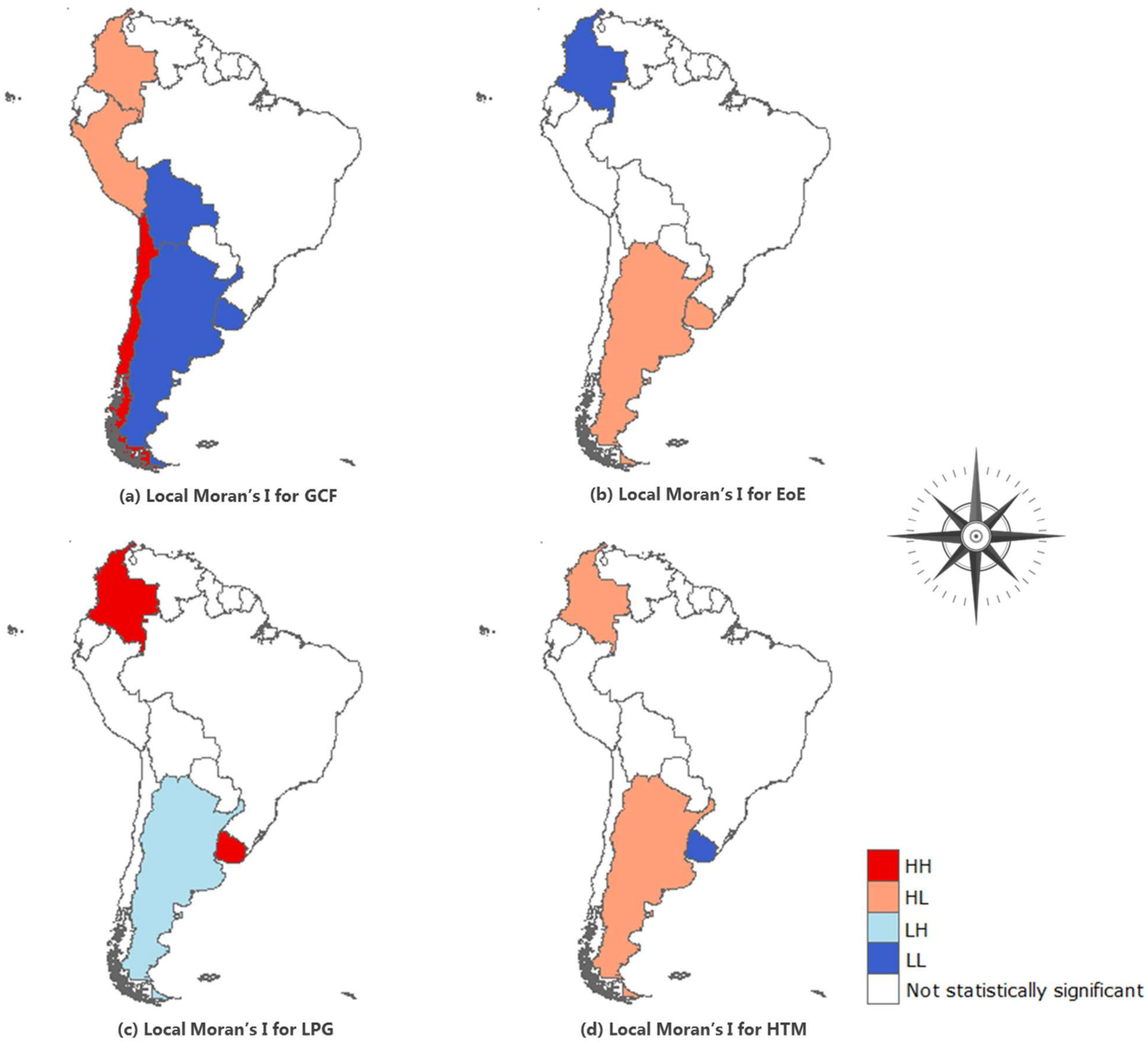

Figure 4 – Local *Moran's I* Maps

This paper contributes to both theory and practical application. On the theoretical side, three of the four research hypotheses confirmed no spatial randomness between innovation performance and the annual growth rate of ISO 9001 certifications across South American countries. On the practical side, the ESDA results suggest that the increase in ISO 9001 certificates can be more associated with market issues than local development policies. This is consistent with the idea that the adoption of ISO 9001 in a country can be motivated by market pressures (Prakash and Potoski, 2006). The findings also highlight the applicability of the ESDA approach for topics related to operational excellence.

Methodologically, our research is novel because we implemented an exploratory study on the effect of innovation performance and ISO 9001 certification in different countries through ESDA techniques. The small number of countries and observations, the absence of data from some countries, and the use of secondary data represent the main limitations of this study. However, replication of our methodological procedure for other regions and countries could expand the findings of this paper. Future research can use our approach to explore the relationship between the other performance indicators and other ISO standards, *e.g.*, ISO 14000, ISO 22000, ISO 45000, and so forth.

REFERENCES

Aarts, F.M., and Vos, E. (2001), "The impact of ISO registration on New Zealand firms' performance: a financial perspective", The TQM magazine, Vol. 13, No. 3, pp. 180-191.

Al-Khalifa, A.K.N. and Aspinwall, E.M. (2000), "The development of total quality management in Qatar", The TQM Magazine, Vol. 12 No. 3, pp. 194-204.

Almeida, E. Econometria espacial. Campinas: Editora Alínea, 2012.

Anttila, J., and Jussila, K. (2017), "ISO 9001: 2015–a questionable reform. What should the implementing organisations understand and do?", Total Quality Management & Business Excellence, Vol. 28, No. 9, pp. 1090-1105.

Benner, M.J., and Tushman, M. (2002), "Process management and technological innovation: A longitudinal study of the photography and paint industries", Administrative science quarterly, Vol. 47, No. 4, pp. 676-707.

Boiral, O. (2003), "ISO 9000: Outside the iron cage", Organization science, Vol. 14, No. 6, pp. 720-737.

Bounabri, N., El Oumri, A.A., Saad, E., Zerrouk, L., and Ibnlfassi, A. (2018), "Barriers to ISO 9001 implementation in Moroccan organizations: Empirical study", Journal of Industrial Engineering and Management, Vol. 11, No. 1, pp. 34-56.

Brunsdon, C., and Comber, L. (2014), "An introduction to R for spatial analysis and mapping". Sage, London.

Cao, X., and Prakash, A. (2011), "Growing exports by signaling product quality: Trade competition and the cross-national diffusion of ISO 9000 quality standards", Journal of policy analysis and management, Vol. 30, No. 1, pp. 111-135.

Corbett, C.J., Montes-Sancho, M.J., and Kirsch, D.A. (2005), "The financial impact of ISO 9000 certification in the United States: An empirical analysis", Management science, Vol. 51, No. 7, pp. 1046-1059.

El Manzani, Y., Sidmou, M.L., and Cegarra, J.J. (2019), "Does IS0 9001 quality management system support product innovation? An analysis from the sociotechnical systems theory", International Journal of Quality & Reliability Management, Vol. 36, No. 6, pp. 951-982.

Escanciano, C., Fernández, E., and Vazquez, C. (2002), "Linking the firm's technological status and ISO 9000 certification: results of an empirical research", Technovation, Vol. 22, pp. 509–515.

Fonseca, L. (2015), "From Quality Gurus and TQM to ISO 9001: 2015: a review of several quality paths", International Journal for Quality Research, Vol. 9, No. 1, pp. 167-180.

Gotzamani, K.D., and Tsiotras, G.D. (2002), "The true motives behind ISO 9000 certification: their effect on the overall certification benefits and long term contribution towards TQM", International Journal of Quality & Reliability Management, Vol. 19, No. 2, pp. 151-169.

ISO Survey (2022), The ISO Survey 2020, International Organization for Standardization, Geneva. available at: https://www.iso.org/the-iso-survey.html (accessed 15 March 2022).

Kopczewska, K., and Kubara, M. (2020), Spatial weights matrix, distance measurement, tessellation, spatial statistics. In "Applied Spatial Statistics and Econometrics", Routledge, New York, NY.

Kopstein, J.S., and Reilly, D.A. (2000), "Geographic diffusion and the transformation of the postcommunist world", World politics, Vol. 53, No. 1, pp. 1-37.

Läpple, D., Renwick, A., and Thorne, F. (2015), "Measuring and understanding the drivers of agricultural innovation: Evidence from Ireland", Food policy, Vol. 51, pp. 1-8.

Lee, K. S. and Palmer, E. (1999), "An empirical examination of ISO 9000-registered companies in New Zealand. Total quality management", Vol. 10 No. 6, pp. 887-899.

Li, L., Hong, X., and Peng, K. (2018), "A spatial panel analysis of carbon emissions, economic growth and high-technology industry in China", Structural Change and Economic Dynamics, Vol. 49, 83-92.

Lo, C.K., Yeung, A. C., and Cheng, T.C.E. (2009), "ISO 9000 and supply chain efficiency: empirical evidence on inventory and account receivable days", International Journal of Production Economics, Vol. 118, No. 2, pp. 367-374.

López-Mielgo, N., Montes-Peón, J.M., and Vázquez-Ordás, C., (2008), Innovation, ISO certification, and quality normalization in the food industry. In: Ruth Rama (Ed.), Handbook of Innovation in the Food and Drink Industry. The Haworth Press, New York.

Magd, H., and Curry, A. (2003), "An empirical analysis of management attitudes towards ISO 9001: 2000 in Egypt", The TQM magazine, Vol. 15, No. 6, pp. 381-390.

Manders, B., de Vries, H.J., and Blind, K. (2016), "ISO 9001 and product innovation: A literature review and research framework", Technovation, Vol. 48, pp. 41-55.

Marash, S.A., and Marquardt, D.W. (1994), "Quality, standards, and free-trade", Quality Progress, Vol. 27, No. 5, pp. 27-30.

Ngai E.W.T. and Cheng, T.C.E. (1997), "Identifying potential barriers to total quality management using principal component analysis and correspondence analysis", International Journal of Quality & Reliability Management, Vol. 14 No. 4, pp. 391-408.

O'Neill, P., Sohal, A., and Teng, C.W. (2016), "Quality management approaches and their impact on firms′ financial performance–An Australian study", International Journal of Production Economics, Vol. 171, No. 3, pp. 381-393.

Piatkowska, S. J., Messner, S. F., and Yang, T. C. (2018), "Xenophobic and racially motivated crime in belgium: exploratory spatial data analysis and spatial regressions of structural covariates", Deviant behavior, Vol. 39, No. 11, pp. 1398-1418.

Prajogo, D.I., and Sohal, A.S. (2004), "The multidimensionality of TQM practices in determining quality and innovation performance: an empirical examination", Technovation, Vol. 24, No. 6, pp. 443–453.

Prakash, A., and Potoski, M. (2006), "Racing to the bottom? Trade, environmental governance, and ISO 14001", American journal of political science, Vol. 50, No. 2, pp. 350-364.

Saraiva, P. M., and Duarte, B. (2003), "ISO 9000: some statistical results for a worldwide phenomenon", Total Quality Management & Business Excellence, Vol. 14, No. 10, pp. 1169-1178.

Sampaio, P., Saraiva, P., and Guimarães Rodrigues, A. (2009), "An analysis of ISO 9000 data in the world and the European Union", Total Quality Management, Vol. 20, No. 12, pp. 1303-1320.

Sharifi, M., McCombs, G. B., and Hosseini, A. (1999), "A strategy for incorporting ISO 9000 into an internationally oriented accounting practice", International Journal of Applied Quality Management, Vol. 2, No. 2, pp. 271-277.

Shi, Y., Lin, W., Chen, P.K., and Su, C.H. (2019), "How can the ISO 9000 QMS improve the organizational innovation of supply chains?, International Journal of Innovation Science, Vol. 11, No. 2, pp. 278-298.

Simao, L., and Franco, M. (2018), "External knowledge sources as antecedents of organizational innovation in firm workplaces: a knowledge-based perspective", Journal of Knowledge Management, Vol. 22, No. 2, pp. 237-256.

Simmons, B.L., and White, M.A. (1999), "The relationship between ISO 9000 and business performance: does registration really matter?, Journal of Managerial Issues, Vol. 11, No. 3, pp. 330-343.

Sohn, S.Y., Kim, D.H., and Jeon, S.Y. (2016), "Re-evaluation of global innovation index based on a structural equation model", Technology Analysis & Strategic Management, Vol. 28, No. 4, pp. 492-505.

Sroufe, R., and Curkovic, S. (2008), "An examination of ISO 9000: 2000 and supply chain quality assurance", Journal of operations management, Vol. 26, No. 4, pp. 503-520.

Taylor, W.A. (1995), "Organizational differences in ISO 9000 implementation practices", International Journal of Quality & Reliability Management, Vol. 12, No. 7, pp. 20-27.

Terziovski, M., and Guerrero, J. L. (2014), "ISO 9000 quality system certification and its impact on product and process innovation performance", International Journal of Production Economics, Vol. 158, pp. 197-207.

WIPO, World Intellectual Property Organization (2021). Global Innovation Index 2021: Tracking Innovation through the COVID-19 Crisis. Geneva: World Intellectual Property Organization, available at: https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2021.pdf (accessed 29 March 2022).

Woolthuis, R. K., Lankhuizen, M., and Gilsing, V. (2005), "A system failure framework for innovation policy design", Technovation, Vol. 25, No. 6, pp. 609-619.

Systemic use of quality tools in HIV/AIDS research project

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ABSTRACT

Purpose - In innovative research to study PrEP, the HIV pre-exposure prophylaxis, field protection medication for 15 to 19 years old, there is a difficulty in organizing the process of recruiting participants, as well as enhancing the number of participants in the cohort. Quality tools can be used to identify these characteristics and the correct use of the strategy, the main objective of this article being.

Design/methodology/approach – With the help of a literature review, quality tools were applied and used in the recruitment processes

Findings - The diagrams created the recruitment flowchart and implemented digital selection sheet to monitor the data, after completing the histogram, control chart, hist and dispersion charts (Cp= 0,82, Cpk=0,30, Pp=0,84, Ppk=0,31). Due to the capacity of a graphical adjustment plan, it was possible to create a cause-and-effect diagram as result to continuous and audited adjustment action plan.

Research limitations/implications- There was difficulty in collecting research data due to the lack of organization of the people who collected it.

Practical implications- As it is dynamic research involving young people of a reduced age group, there were difficulties in understanding the field of recruitment and applying the tools.

Social implications- There is great difficulty in accessing young people from 15 to 17 years old, as they need their parents' authorization to enter the research.

Originality/value - One of the challenging processes is recruiting new participants, requiring constant innovations and improvements due to the specifics of the target audience and the dynamics of the field of study.

Keywords: Healthcare, Strategy and Organizational Engineering, Quality Management

Paper type: Case study

INTRODUCTION

Global efforts to strengthen HIV prevention and treatment programs are also reducing the transmission of HIV. Since 2010, the annual number of new HIV infections (all ages) has declined by 16% to 1.8 million and new infections declined among young men (aged 15–24 years) during that time, falling by 16% to 250 000 [110 000–320 000] in 2016 (UNAIDS, 2017). One form of prevention of this virus is the adoption of antiretroviral drugs, such as PrEP, also called pre-exposure prophylaxis. And when ingested a pill a day, the patient is immune to the HIV, its effectiveness having been demonstrated when there is high adherence (FONNER, V. A. et al, 2016). Demonstrating the effectiveness of PrEP in young adolescents is one of the objectives of the PrEP 15-19 Brazil survey. The protocol is similar to PrEP for adults, with several tests - including HIV testing, general health assessment, filling out a socio-behavioral questionnaire, and answering questions. If they have an indication for PrEP and are willing to participate, the adolescent signs a consent form, receives medication, and condoms, and returns scheduled for 30 days. Follow-up is quarterly with clinical and laboratory examinations to assess the presence of STIs and whether HIV infection has occurred. Several methods are used and addressed in HIV/AIDS research involving recruitment. For the vulnerable population, such as those 15 to 19 years old, men who have sex with men, transsexuals, and transvestites, studies and recruitment approaches in the literature are still incipient and superficial. The implementation and subsequent improvement of all possible ways of reaching the target audience of the research with a focus on health allow: (i) helps in the dissemination of project information; (ii) the replication of the best actions, and (iii) the allocation of investments in the strategies that provide results. Besides, the improvement of existing strategies with more people recruited and a higher quality of study and treatment of STIs to HIV infections. This study shows the evolution and improvement of the quality tools and the quality engineering concepts of the strategies used in the recruitment for the PrEP 15-19 survey in Brazil, Salvador website.

RESEARCH METHODOLOGY

The manuscript is based on database from a research project focused on HIV/AIDS. It is intended to create a qualitative and quantitative evaluation model that can be used in future projects. Thus, the solution to a practical problem is sought and a new method for predictive evaluation is created, thus characterizing the research as of an applied nature.

The quantitative character of the research is verified in the use and analysis of data to build a model for improvement, forecasting, and prediction. From the point of view of its objectives, it has an explanatory character. It aims to study and understand the behavior of recruitment data, taking the form of an ex-post-facto survey. The technical procedures will follow the research pattern where the object of study is the recruitment values, and variables that influence their behavior will be analyzed.

There is also a theoretical reference study to support and direct the use of the tools. Quality management can be introduced by the 7 classic quality tools - referenced in Table 1- and the other methodological derivation tools that play in organizations.

Table 1 - References of Classic Quality Tools

Quality Tool Name	Theoretical Reference
Stratification	[...] Stratification is a division of a given group of data into several subgroups according to the desired factors, which are known as stratification factors (WERKEMA, 1995). According to Tague (2004), a technique that separates data gathered from a variety of sources so that patterns can be seen (some lists replace stratification with flowchart or run chart).
Verification Sheet	[...] The verification sheet consists of facilitating, organizing, and standardizing the collection and recording of data so that the subsequent compilation and analysis of the data is optimized (WERKEMA, 1995). The data it captures can be quantitative or qualitative. When the information is quantitative, the check sheet is sometimes called a tally sheet (SCHULTZ, 2006).
Pareto Chart	"[...] The Pareto chart is a bar chart in which they are ordered from the highest to the lowest, and a curve is drawn that shows the accumulated percentages of each bar (WERKEMA, 1995). According to Juran (2000), in the Pareto Graph, values in percentage and the accumulated value of occurrences are often included. Thus, it is possible to evaluate the cumulative effect of the searched items regardless of the order of the bars. The Pareto principle establishes that a problem is mainly caused by a reduced number of causes. These must be identified and then actions taken to eliminate them at first, which will already mean a reduction of 80 or 90% of the causes. A bar chart that organizes the data from largest to smallest to direct attention on the important items. It visually highlights which situations/problems are more significant (KARDAS, 2017). losses that the company has been suffering, and then dedicate itself to eliminating the other reasons that have little contribution to the problem, which will make the problem be solved in a much more efficient way (TRIVELLATO, 2010)."
Cause and Effect Diagram	[...] the cause and effect diagram is a tool used to present the relationship between a result of a process (effect) and the factors (causes) of the process that, for technical reasons, may affect the considered result (WERKEMA, 1995). For Ishikawa (1990), the constraint due to hierarchical (non-relational) structure is often irrelevant, especially in early approaches.
Histogram	In order to present the elements which had to be fixed to improve the product quality and obtain customer satisfaction, in the brainstorming session a classic instrument of quality management was used, the histogram (TAGUE, 2004). [...] histogram is a bar graph in which the horizontal axis, subdivided into several small intervals, presents the values assumed by variables of interest (WERKEMA, 1995).
Scatter Chart	[...] the Scatter Chart is a chart that shows the type of relationship between two variables, through which it is possible to identify if there is a trend of joint variation (correction) between two or more variables (WERKEMA, 1995). Graphs pairs of numerical data, one variable on each axis, to look for a relationship (TAGUE, 2004)

Control Chart	[...] Control charts are tools for monitoring variability and evaluating process stability (WERKEMA, 1995). *C* charts are used to look at variation in counting type attributes data. They are used to determine the variation in the number of defects in a constant subgroup size (MONTGOMERY, 2012).

Basic techniques such as brainstorming¸ 5 Whys, affinity diagram, 5W1H, and 6M are used to help the members of the Quality Control Circle to think creatively (FALCONI, 2009). Several other quality tools are used in various companies, such as the PDCA Cycle: Plan, Do, Check and Action (MARANHÃO, 2002). This tool is considered a management model in problem-solving. There is a tendency to use the SDCA Cycle before PDCA (Standard, Do, Check, Action), which summarizes the standardization of the process before applying an improvement, starting with the PDCA Plan (FALCONI, 2009). The union between the two systems leads to a global cycle of two smaller cycles, which translates into the meaning of continuous improvement of processes, an assumption of Quality Assurance. Due to these characteristics, the SDCA focuses on Keeping what was interesting in the process and the PDCA focuses on improving what the process needs to increase its production efficiency.

Table 2 - Theoretical reference of quality tools to support the PDCA cycle

Quality Tool Name	Theoretical Reference
5 Why	According to the Asian Development Bank (2019) [...] is an iterative interrogative technique used to explore the cause-and-effect relationships underlying a particular problem... The primary goal of the method is to determine the root cause of a defect or problem by repeating the question "Why?". Each answer forms the basis of the next question. The "five" in the name derives from an anecdotal observation of the number of iterations needed to resolve the problem.
Verification Sheet	[...] is a business tool used to organize ideas and data ... the tool is commonly used within project management and allows large numbers of ideas stemming from brainstorming to be sorted into groups, based on their natural relationships, for review and analysis (SPOOL, 2004)
5 W 1 H	"[...] can be defined as an organized document that identifies the actions and responsibilities of those who will perform it, through a questioning, capable of guiding the various actions that must be implemented, and must be structured to allow quick identification of the elements necessary for the implementation of the project (RIBEIRO & BLIACHERIENE, 2013).
6 M	[...] diagram grouping as causes in 6 M (labor, method, raw material, measure and environment) and the result of the diagram is the result of a brainstorming (significant of ideas), that is, thoughts and ideas that each member of a discussion group exposed without and democratically (MIGUEL, 2006)

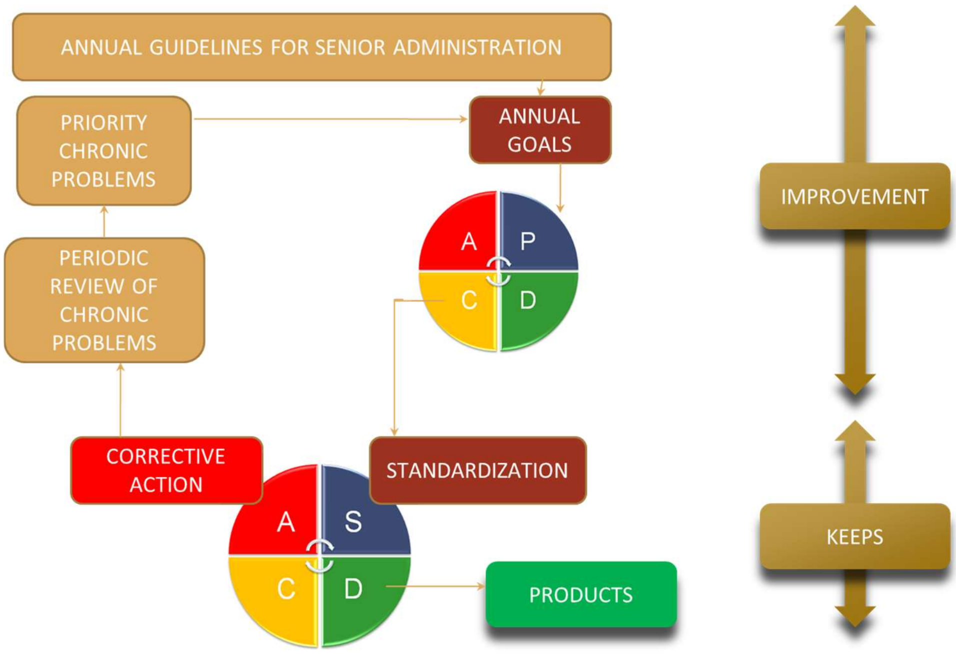


Figure 1 – Schematic process of SDCA and PDCA (FALCONI, 2009)

For this model, the company defines annual guidelines and transforms them into goals, which will later be achieved with process improvements. If there is a new process to be implemented, there is standardization with mapping this process and its description in SOP (standard operating procedure). This results from the SDCA Cycle, replacing the P of PDCA (Plan) with the S of Standard (standardization). If this same process is modified or improved, the need is transmitted to the PDCA, generating an improvement instead of standardization.

Quality tools must serve as activities where improvement follows the resolution of product and process problems. There should be corrective actions for analyses carried out in working groups, Kaisen, DFMEA (Design Failure Modes and Effects Analysis), or TPM (Total Productive Maintenance). It is hoped that the problems identified with these methodologies do not occur again with the preventive actions that will be addressed and executed. This reality is becoming more and more incipient, due to inaccuracies of information, mistaken analysis, or even operational inefficiency. Without real knowledge, the tools will also not follow an objective line of solving problems and anomalies (FALCONI, 2009).

RESULTS AND DISCUSSION

The new methodological proposal to improve HIV/AIDS surveys indicators in recruitment processes stems from the real need to measure the operations results in all recruitment strategies areas. The recruitment process can be defined in figure 8. Each stage of it must contain an indicator, at least, that explains it and manages to measure the reflection of the actions of the stage and how they will interfere with the others. Recruitment strategies must also be measured and reflected in performance evaluation indicators.

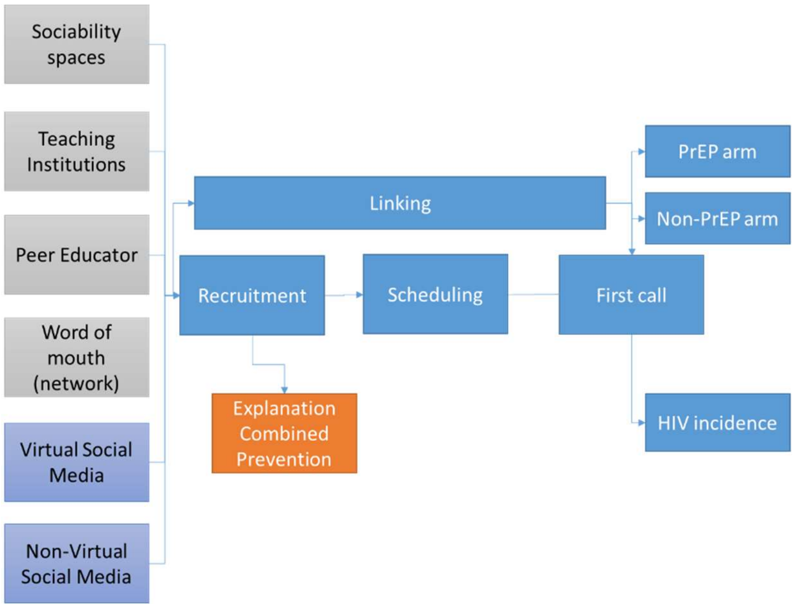


Figure 2 – Full recruitment process flow for the site Salvador in Brazil

To use quality tools in improving strategies, it is necessary to study the entire recruitment process and see what would be the most effective approaches and which will bring more results. In other words, the focus is on prioritizing the methodologies to: (*i*) which ones would be more effective; (*ii*) would get more impact on the recruitment results of absolute values; and (*iii*) which would bring more treatment of STIs and prevention with the ingestion of PrEP (in this specific case, with the prevention treatment of contamination with HIV).

For this approach, it is necessary to see the database as one of the quality tools, the check sheet. This case would be the process control and monitoring worksheets and their removal by the project's general information system, SiSPrEP.

Information Record - Check Sheet: of the forms of data insertion, for this study, only the sources were considered:

I. *Worksheets to be filled in by peer educators* – These are ways of recording daily recruitment information by peer educators, who manage the insertion of this data.

Table 2 - Check sheet being used as traceability and recruitment record by Peer Educators

Recruitment Traceability									
First stage								*Second stage*	
Participant	**Recruitment Form**	**Appointment Date**	**Month**	**Recruitment Date**	**Gender**	**Sexuality**	**Age**	**Confirmation performed?**	**Remarcação**
Participante 1	**Formative Research**	**23/04/2019**	April	16/04/2019	cisGender	homosexual	**17**	**No**	**Participant Present**
Participante 2	**Formative Research**	**23/04/2019**	April	17/04/2019	cisGender	homosexual	**16**	**No**	**Pending Redial**
Participante 3	**Formative Research**	**18/04/2019**	April	18/04/2019	cisGender	homosexual	**19**	**No**	**Participant Present**
Participante 4	**Event and Actions**	**16/04/2019**	April	16/04/2019	cisGender	homosexual	**19**	**No**	**Participant Present**
Participante 5	**Peer Educator Network**	**17/04/2019**	April	17/04/2019	cisGender	homosexual	**18**	**No**	**Participant Present**
Participante 6	**grindr**	**23/04/2019**	April	18/04/2019	cisGender	pansexual	**19**	**Yes**	**Pending Redial**
Participante 7	**Peer Educator Network**	**24/04/2019**	April	19/04/2019	cisGender	homosexual	**19**	**Yes**	**Pending Redial**
Participante 8	**Instagram**	**24/04/2019**	April	24/04/2019	cisGender	homosexual	**19**	**No**	**Participant Present**
Participante 9	**Peer Educator Network**	**25/05/2019**	April	25/04/2019	cisGender	homosexual	**18**	**No**	**Participant Present**
Participante 10	**Participant Indication**	**26/04/2019**	April	26/04/2019	cisGender	homosexual	**17**	**Yes**	**Pending Redial**
Participante 11	**Peer Educator Network**	**26/04/2019**	April	26/04/2019	cisGender	homosexual	**18**	**No**	**Participant Present**
Participante 12	**Spontaneous Demand**	**26/04/2019**	April	26/04/2019	cisGender	homosexual	**19**	**No**	**Participant Present**
Participante 13	**Instagram**	**26/04/2019**	April	27/04/2019	cisGender	bisexual	**17**	**No**	**Pending Redial**
Participante 14	**Peer Educator Network**	**29/04/2019**	April	28/04/2019	cisGender	homosexual	**18**	**Yes**	**Pending Redial**
Participante 15	**Peer Educator Network**	**30/04/2019**	April	29/04/2019	cisGender	homosexual	**18**	**Give up**	**Pending Redial**
Participante 16	**Instagram**	**30/04/2019**	April	30/04/2019	cisGender	homosexual	**17**	**No**	**Pending Redial**
Participante 17	**Peer Educator Network**	**30/04/2019**	April	**30/04/2019**	cisGender	homosexual	**19**	**No**	**Participant Present**
Participante 18	**Instagram**	**03/05/2019**	**May**	**03/05/2019**	cisGender	bisexual	**19**	**Yes**	**Participant Present**
Participante 19	**Peer Educator Network**	**02/05/2019**	**May**	**04/05/2019**	cisGender	homosexual	**17**	**Yes**	**Pending Redial**
Participante 20	**Peer Educator Network**	**02/05/2019**	**May**	**05/05/2019**	cisGender	homosexual	**18**	**Yes**	**Pending Redial**

II. *SiSPrEP* – An information system that manages all research data. Over time, it was found that the information was still not reliable for the year and months of the study. An audit was then carried out on the qualitative, quantitative, and statistical data to verify what was consistent with the records and what was overestimated. After the corrections, checks were carried out with the other documents, such as the peer educators' worksheets.

III. *Registration by the Participants' reception sector* – there is another form of verification sheet on the Salvador website for registration of recruitment carried out in the reception and registration of new participants. At this moment, the participant is asked about the primary source of recruitment and other important data to link the participant to the research, such as gender identity, sexual orientation, age, date of birth, and contact.

After auditing the data from all forms of records, the main product and the whole recruitment database was the monthly performance photograph of the numbers of people recruited throughout the year. This is the starting point for the other analyses to improve the strategies since all the established goals were not reached. In addition, it was necessary to categorize some study variables according to Tables 3 and 4.

Table 3 - Categorization of the forms of recruitment to carry out the evaluations

Summarized Recruitment Forms	Expanded Recruitment Forms	Category
Peer Educators	Events and actions; Peer Educator Network	1
Social media	All Social Media	2
Mouth to mouth	Participant nomination; Formative Research; Site Contacts Network; Spontaneous demand	3

Table 4 – Categorization of the macro-regions of residence of the participants for carrying out the analyses.

Macro Region of Salvador	Category
Seafront	1
Rail Suburb	2
Periphery	3
Downtown	4
Metropolitan Region of Salvador	5
Uninformed	6

The behavior of Recruitment Variables: Scatterplot, Histogram, Control Charts, Stratification, and Pareto diagram

The way to mirror the actions and their results would be in the form of indicators and graphs that show the behavior of the strategies and methods used in the project. The order itself is not the priority but the subsequent analysis of the construction of these graphs. However, for a better understanding of the behavior, a non-directional flow was created to use these 4 tools, as shown in Figure 3.

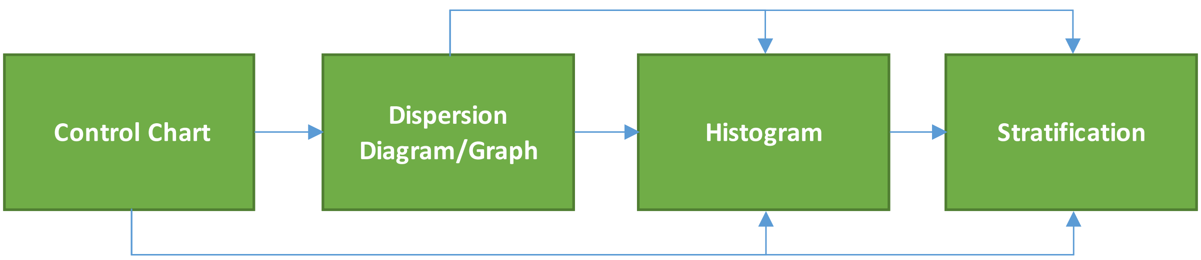
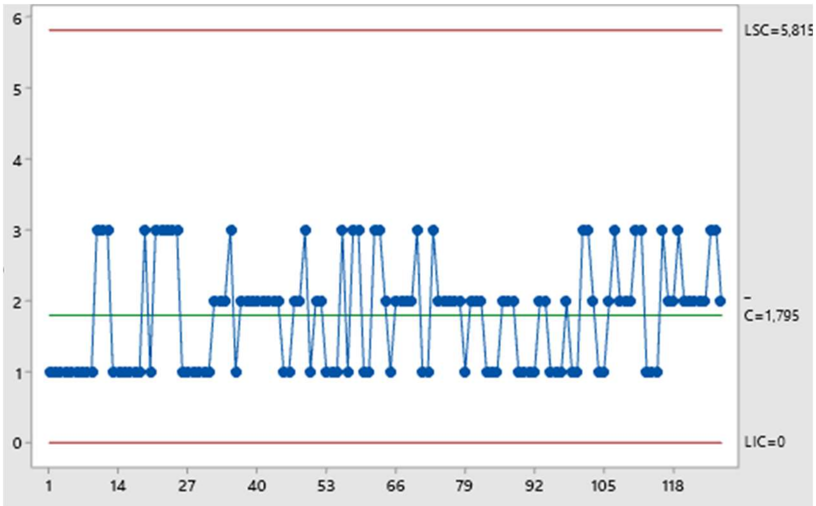


Figure 3 – Data inclusion process to verify indicators and variable behavior.

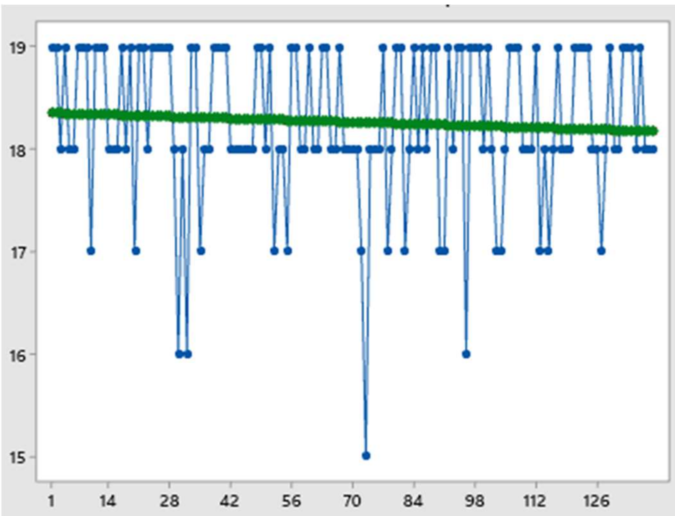
- *Control Charts*

One of the main criteria for entering project participants in the eligibility analysis is age. The PrEP 1519 project only includes people aged 15 to 19. Thus, having a sample as homogeneous as possible by the age criterion is, without a doubt, one of the great challenges of the project.

After plotting the collected data using the control chart for attributes (c-Chart), we identified statistical control trends. A letter without the trend and with the trend was made to understand better how recruitment strategies are managing to be effective in finding younger people. The dominance of 18 and 19 year olds is still a reality, but there is a tendency for minors to enter the research.



(a)

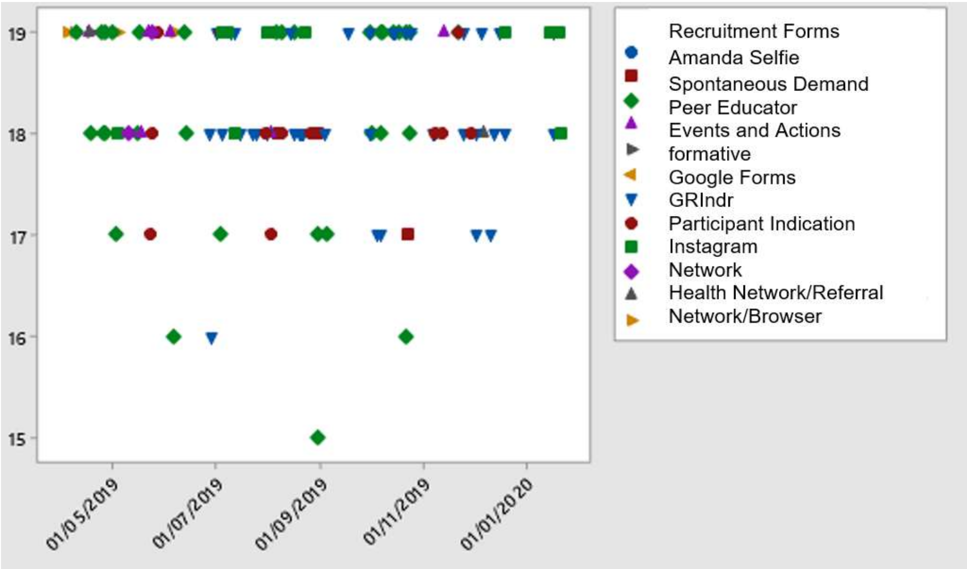


(b)

Figures 4 - Control charts without (a) and with (b) trend line for the age variable (by vertical)

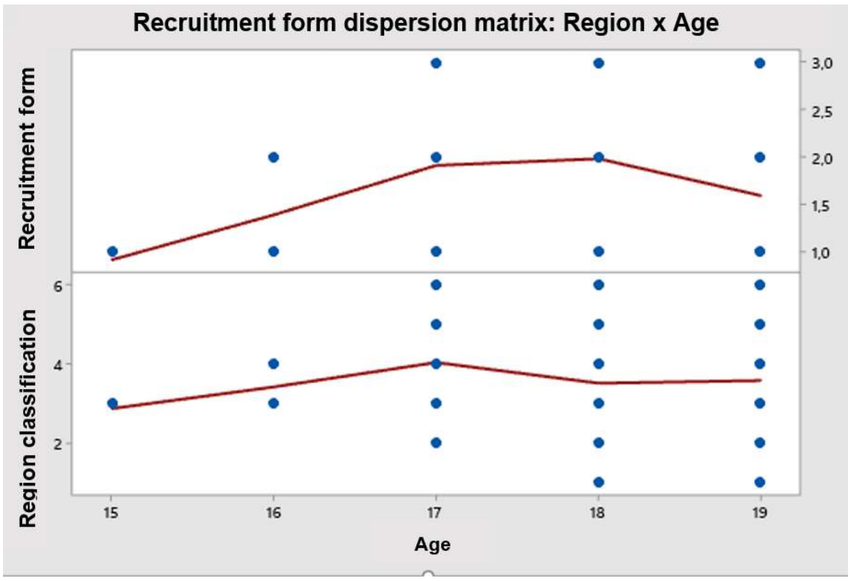
- *Scatter diagram*

The first dispersion used for analysis must be done with the critical variables of the project. Age and forms of recruitment are two of them. This dispersion can be identified in Figure 5. The predominance of the peer educator recruitment method is notorious, followed by Grindr (relationship application).



Figures 5 – Scatter diagram with age variables and forms of recruitment

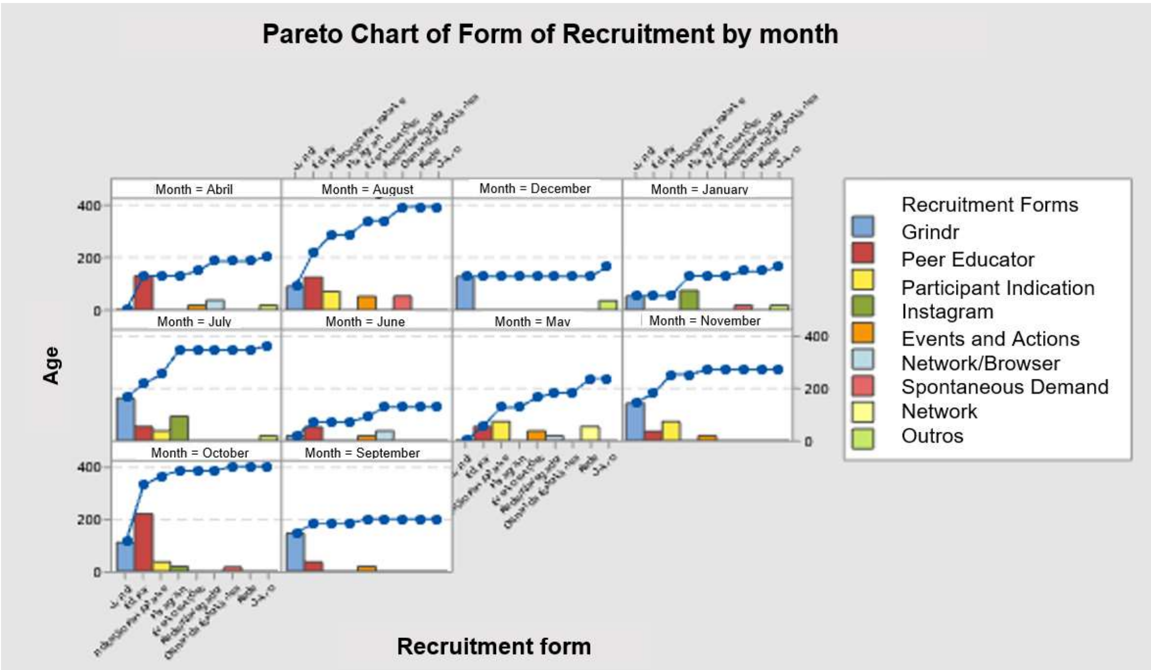
Other trend analyses for the scatter diagram were made with the variables form of recruitment, understanding the relationship of macro-region of residence of the participants and their age. This tool shows that the trend of the recruitment' forms and the regions of residence according to the age of the participants. Minors tend to be recruited in ways 1 to 2 and are in regions 2 to 4. The older adults, most of the project participants in the Salvador site, tend to be recruited in ways 2 to 3 and are located between regions 2 to 4, with a concentration in region 3.



Figures 6 - Scatter diagram with age variables and forms of recruitment

- *Pareto diagram*

The monthly Pareto chart is used to understand the distribution over the months in a structured way. The prioritization of strategies for future investments of efforts will be in the Grindr relationship application and the peer educators network strategy, represented by blue and red colors, respectively. Through a greater unfolding, the research can also provide, which occurred in May. There was a greater proportional distribution of available recruitment strategies. This may indicate seasonality or, for this month, differentiated actions provided the emergence of new participants in the survey for the less effective strategies in the other months.



Figures 7 - Pareto charts by month with the deployment of strategies.

- *Histogram*

In the description for the histogram, several analyses were performed with one of the main study variables, which is the age of the participants. First, the data were plotted on the histogram with a normal curve to verify the normality and the behavior of this variable. After that, interpreting the capacity of the process and the trend of change from the CpK and Cp based on age, with maximum and minimum limits, 19 and 15 years, respectively, would be the main products for analysis of this tool.

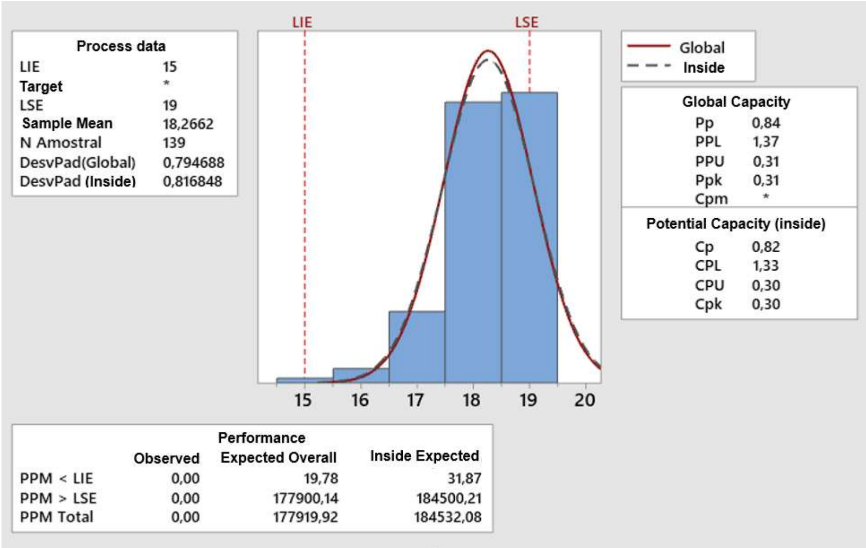


Figure 8 – Histogram representing the age distribution of project participants.

Since Cp < 1 and CpK << 1, the process can be considered effective and potentially not decentralized capable. The Pp < 1 and the PpK << 1 also infer the global insufficiency to the process due to its variability when comparing the specification limits. This imposes the difficulties of reaching the layers of the population at risk from 15 to 17 years old to centralize the normal curve and project a Cp greater than 1 and the behavior of the process in the future. Suppose there are no changes in recruitment strategies and methodologies. In that case, there will always be a greater number of participants between 18 and 19 years old (by Brazilian legislation, they are their legal guardians) and a smaller number of participants between 15 to 17 years old. The latter needs formal authorization from legal guardians and characterizes greater difficulty in accessing health education.

- *Stratification of Cause Analysis: Ishikawa Diagram*

After measurements have been carried out, it is necessary to analyze the cause of the low performance in the number of people recruited when evaluating the study population. The Ishikawa diagram demonstrates this stratification with the possible reasons that were addressed in constructing a model of strategies to get new participants for the project, as shown in Figure 9.

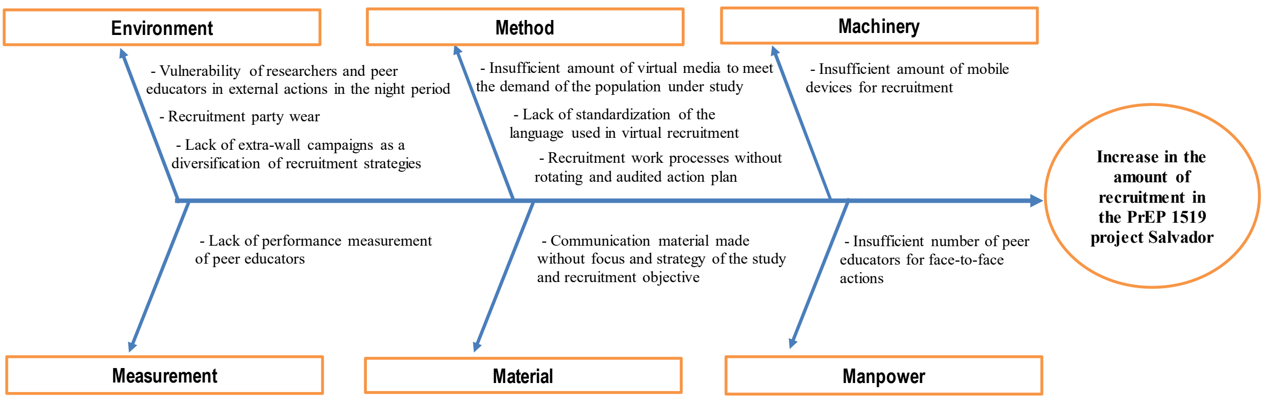


Figure 9 – Cause/Effect Diagram of possible causes of non-reach of new PrEP 15-19 project participants at the study site in Salvador.

- *Root Cause Analysis and Action Plan: 5WHY and 5W2H*

After stratification, the proposed model directs the use of a fundamental cause analysis tool that, in this project, is exemplified by the 5 whys. In it, the questions were divided by each "M" of the 6 M's of the Ishikawa diagram. At the end of each why, an action to prevent or correct the main causes is assigned.

Table 5 – Cause analysis using the 5 why method

Causes	6 M	Why?	Reason	What to do?
I	Method	**Insufficient amount of virtual media to meet the demand of the population under study**	There is a lack of study of possible media that collaborate with research recruitment	Conduct a study of existing social media in the market
		Why is there a lack of study of possible media that collaborate with research recruitment?	Lack of knowledge of media that can contribute to the quantitative increase of the target audience in the research	Diversify virtual media for active recruitment
II	Method	**Recruitment work processes without rotating and audited action plan**	Lack of continuous management methodology in meetings and the work routine	Implement routine management in recruiting new participants
III	Mother-nature	**Vulnerability of researchers and peer educators in external actions in the night period**	Prejudice associated with the lack of information generates insecurity in the recruitment approaches by peer educators	Prioritize virtual environments in recruitment strategies
		Why is Prejudice associated with the lack of information that generates insecurity in the recruitment approaches by peer educators?	Team with a diversity of gender, ideas, and positions	
IV	Mother-nature	**Recruitment party wear**	Reaching the same audience frequently at the same parties	Carry out a strategic study of new recruiting possibilities outside the walls
		Why Reach the same audience frequently at the same parties?	Lack of diversification of recruitment strategies using spaces outside the clinic and in a virtual way	

V	Measurement	**Lack of performance measurement of peer educators**	Lack of a performance management and results monitoring system	Implement routine management in recruitment
VI	Material	**Communication material made without focus and strategy of the study and recruitment objective**	Lack of periodic meetings to align recruitment and project communication needs	Add project communication to the recruitment management model
VII	Manpower	**Insufficient number of peer educators for face-to-face actions**	There was no headcount study to measure the real need to achieve the project's established goals	Review assignments and routines of peer educators
				Recruit new peer educators
VIII	Machinery	**Insufficient amount of mobile devices for recruitment**	Lack of knowledge of the web environment to use applications on more than one screen	Prioritize recruitment through web environments
IX	Mother-nature	**Lack of extra-wall campaigns as diversification of recruitment strategies**	There has never been a strong campaign to diversify extramural recruitment strategies	Conduct periodic campaigns as new recruitment strategies
X	Method	**Lack of standardization of the language used in virtual recruitment**	The difference in positioning in approaches to combined prevention and lack of staff training	Standardize form and language in recruitment approaches
				Conduct staff training with the standard method of approach

- *5W1H and decision making*

The final model for decision-making for recruitment processes would be according to figure 10. All steps direct the correct decision-making of improving strategies, increasing the probability of better results since the tools contemplate most of the project's restrictions and feedback to the existing PDCA. The GUT and Effort and Impact matrices were not used because the number of causes raised was insufficient to work on a greater detail of the priorities. It was considered that all causes were addressed as priorities, and the action plans were developed in the 5W1H model (description of the action, responsible for the execution, deadline for completion, how the action will be carried out, the reason why the action was proposed and where it will be carried out).

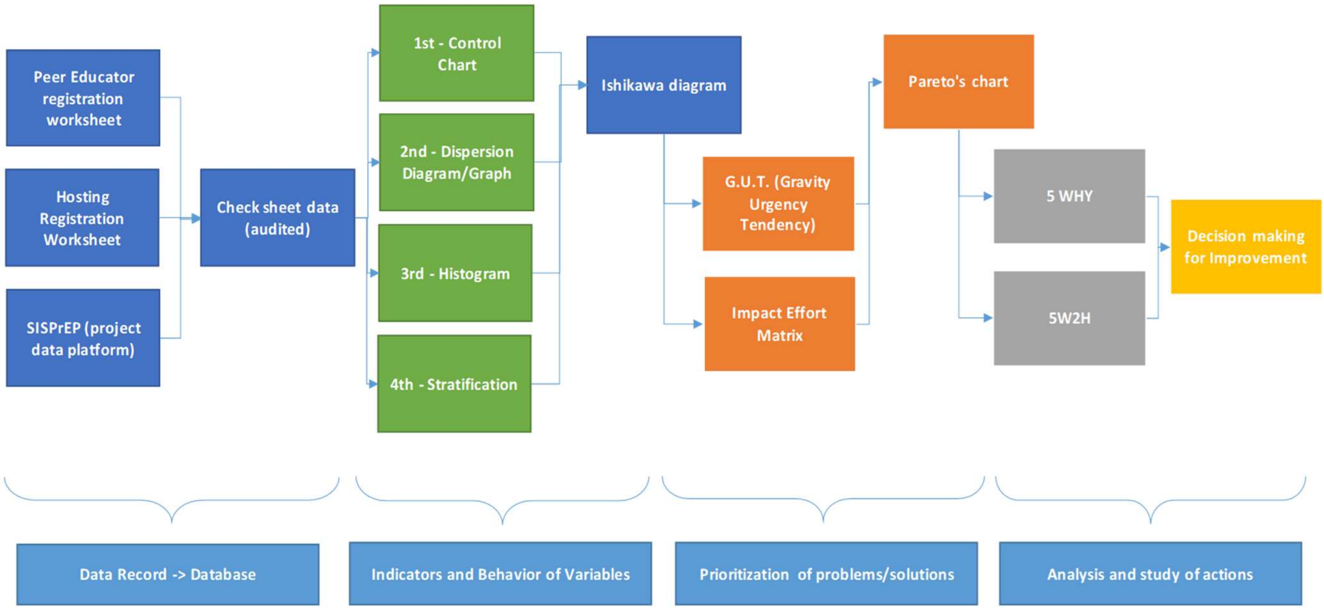


Figure 10 – A proposed model of process for improving recruitment strategies in research using quality tools

CONCLUSIONS

Quality tools provide organizations with better performance and existing direct models to achieve more challenging results supported by solid strategies. Knowing how to handle data and manage the information they translate into the process is one of the challenges of how quality fermentations should be used. The use of quality tools in organizational processes in health research projects is a constant challenge. Depending on the area, use the tool "a" or "b" becomes very dynamic and inconstant. Therefore, the structure proposed as a model for this type of study presented satisfactory results, which appeared with the implemented and improved actions from the management model to provide feedback on future actions. The project not only achieved better performances in the recruitment area but opened up several possibilities for engagement with the various areas that constantly and fully converse with the strategies developed, especially in the virtual environment.

The next steps to finalize the model would be to constantly measure the results achieved and what impacts they brought to the project. The numbers are also important for the permanence of productivity and accountability to the financiers. New perspectives for using the tools may also emerge, so they follow the line of the process that the classic and complementary tools propose to do. This gives the project a unique performance and attributes the results to solid management and gradual improvement.

REFERENCES

Carpinetti, L. C. R. Gestão da Qualidade – Conceitos e Técnicas. São Paulo: Atlas, 2010

Falconi, Vicente. O Verdadeiro Poder. Noiva Lima - INDG Tecnologia e Serviços LTDA, 2009.

Five whys technique. adb.org. Asian Development Bank. February 2009. Retrieved September 5, 2019.

Ishikawa, K. . Introduction to quality control. California: 3A Corporation, 1990.

Schultz, J. R. (2006). "Measuring Service Industry Performance: Some Basic Concepts". Performance Improvement. 45 (4): 3. doi:10.1002/pfi.2006.4930450405.

Juran, J. Juran's quality handbook. New York: McGraw-Hill Professional, 5th ed., 2000.

Kardas, E. (2017). The Analysis of Non-Conformances of Products in Plate Mill Using Selected Quality Tools. In: 26th International Conference on Metallurgy and Materials (METAL 2017), Tanger, Ostrava. ISBN 978-80-87294-79-6

Maranhão, M. ISO série 9000: manual de implementação. 6. ed. Rio de Janeiro: Qualitymark, 2001.

Miguel, P.A.C. Qualidade: enfoques e ferramentas.. 1 ed. São Paulo: Artliber, 2006.

Moreira, Daniel. Administração da produção e operações. São Paulo, Pioneira: 1993.

Montgomery, D.C. (2012). Statistical Quality Control, 7th Edition. Hoboken, NJ (USA): Wiley. ISBN: 978-1-118-14681-1.

Pontes, H. L. J; (2005). Melhoria no sistema produtivo de uma fábrica de café: estudo de caso. In Simpósio de Engenharia de Produção, 12, Bauru. Anais. São Paulo: SIMPEP, 2005

Ribeiro, R. J. B.; Bliacheriene, A. C. Construindo o planejamento público: buscando a integração entre política, gestão e participação popular. São Paulo: Atlas, 2013.

Sachs, Ignacy. A Terceira Margem: em busca do ecodesenvolvimento. São Paulo: Companhia das Letras, 2009.

Spool, J. M. The K-J technique: A Group Process for Establishing Priorities. In User Interface Engineering. May 11, 2004.

Tague, N.R. The Quality Toolbox, Second Edition, American Society for Quality, Quality Press, Milwaukee, Wisconsin, 2004.

Toyota Group; TQM Committee; QC Circle Subcommittee; QC Circle Leader´s Guidebook for Level Identification – How to get out of Zone D or C, Tokyo: JUSE Press Ltd., 2008

Trivellato, A. A. Aplicação Das Sete Ferramentas Básicas da Qualidade no Ciclo PDCA Para Melhoria Contínua: Estudo de Caso numa Empresa de Autopeças. Escola de Engenharia de São Carlos, Universidade de São Paulo, 2010.

UNAIDS. UNAIDS Data 2017. Geneva, Switzerland: UNAIDS; 2017

Werkema, M. C. C. Ferramentas Estatísticas Básicas para o Gerenciamento de Processos. v. 2. Fundação Christiano Ottoni. Escola de Engenharia da UFMG. Belo Horizonte, MG. 1995.

Revisiting European diffusion: ISO 22000 Certification

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STRUCTURED ABSTRACT

Purpose – This paper aims to update and report the diffusion and forecasting model of ISO 22000 certification in Europe.

Design/methodology/approach - A research method similar to that described by Granja *et al*. (2021) was adopted. The results of the ISO 22000 evolution among European countries (ranging from 2007 to 2018) have been updated to consider available data regarding the years 2019 and 2020. The behavior of the number of ISO 22000 certification over the years was studied adopting the Gompertz model.

Findings - The results obtained by fitting the data to this model were dissected enabling a forecast for the forthcoming years. Similarly, encompassing the conclusions of the original study, the diffusion throughout the years of the number of ISO 22000 certificates also presents an S-shaped behavior. This present study also confirms similar behavior between ISO 14001 and ISO 22000 standard diffusion processes.

Research limitations/implications - Despite the new data added to the analysis, the results of ISO 22000 certification behavior in European countries data include uncertainties, and to overcome this lack of data, it is necessary to update it with new data from the forthcoming years.

Originality/value - This paper updates and confirms results presented by Granja *et al*. (2021) encompassing the first study of the ISO 22000 diffusion in Europe over the years.

Keywords: Food Safety, Diffusion model, ISO 22000, Gompertz model.

Paper type: Research paper

INTRODUTION

Despite being world-renowned, research gaps remain unanswered encompassing the dynamic of ISO 22000 certification around the world. This study intends to update the first attempt carried out by Granja *et al*. (2021) to analyze the diffusion process of the ISO 22000 taking into account the data (now available) from the last years.

The compliance with international management standards is a mandatory item for companies that desire to be part of the international food trade (Gil *et al*., 2017). For a better understanding of the worldwide diffusion, several researchers analyzed the spread of well-known standards, such as ISO 9001 and ISO 14001 (Chen and Liu, 2009; Clougherty and Grajek, 2014; Corbett and Kirsch, 2001; Franceschini *et al*., 2006; Franceschini *et al*., 2010; Herzfeld *et al*., 2011; Hikichi *et al*., 2016; Salgado *et al*., 2015; Saraiva and Duarte, 2003; To and Lee, 2014) in order to identify patterns and drivers related to these processes.

Several studies also have a specific approach in order to forecast the behavior of certification (Cabecinhas *et al*., 2018; Cabecinhas *et al*., 2020; Mastrogiacomo *et al*., 2020; Sampaio *et al*., 2011; Franceschini *et al*., 2004; Marimón *et al*., 2008; To and Lee, 2014; Marimón *et al*., 2009; Alonso-Almeida *et al*, 2013). This perspective holds important implications regarding the relevance of the standard to the international trade once a certificate becomes less attractive when the diffusion process of a standard reaches the saturation point (Franceschini *et al*., 2006).

When analyzing the dynamic of ISO 9001 diffusion, Albuquerque *et al*. (2007) evidenced a strong geographic influence in the spread of this standard. In contrast, the authors also stated that the cultural similarity appeared larger for ISO 14000. The involved set of stakeholders and authorities support the dissemination of that international standard.

Although a strong geographic pattern is identified in the diffusion of standards, the main FSMS standards are retail-driven. It is clear the effect of retailers on their suppliers all over the world regarding the compliance with different food safety standards (Havinga, 2013). It must be emphasized that, in the last decades, the global food supply comprises different types of intermediaries and food safety regulations (Bonanno *et al*., 1994).

The research paper is structured as follows: this Introduction section addressed the latest published contributions concerning Food Safety and the diffusion of Management System standards. The Research Methodology is described in the following section and the Results section performs an analysis of the ISO 22000 certification in Europe based on available data. Finally, the Conclusions section, suggestions for future work, and references used in this study are presented.

RESEARCH METHODOLOGY

Once the performance of the reported models is affected by the number of collected observations, the continuous update to check the validity throughout time is a necessity (Meade and Islam, 1998; Cabecinhas *et al*., 2018).

Sample

The data sample was collected from the study of Granja *et al*. (2021) encompassing some additional data from more recent years (2019 and 2020).

Similar to the aforementioned previous study, the data regarding ISO 22000 certification was provided by ISO Survey and ISO 22000 Survey (2007 to 2020) and Table 1 presents the raw data used for constructing the forecasting model. "Counter" value also was considered the independent variable to identify temporal scale.

Table 1 – Data used for constructing the forecasting model.

Year	Counter	Issued ISO 22000 certificates
2007	*1*	*2749*
2008	*2*	*4865*
2009	*3*	*6050*
2010	*4*	*7083*
2011	*5*	*7361*
2012	*6*	*8307*
2013	*7*	*9357*
2014	*8*	*10,181*
2015	*9*	*11,181*
2016	*10*	*11,083*
2017	*11*	*10,342*
2018	*12*	*9666*
2019	*13*	*10,239*
2020	*14*	*9808*

Data analysis: model

Based on the available data and the forecasting model built on Granja *et al*. (2021), it is assumed that the presented model follows an S-shaped curve and, similarly, the Gompertz model was adopted aiming at updating the diffusion of ISO 22000 certification in Europe.

The Gompertz curve is a well-known model to characterize this curve-type behavior (Berny, 1994) and it fits better when applied in regions that have not yet reached the maximum level of saturation (Cabecinhas *et al*, 2018). In addition, the asymmetry of the point of inflection is an important characteristic of the model (Meade and Islam, 2006). This asymmetry represents, approximately, 37% of the final growth (Winsor, 1932). The author also stated an equation to find the inflection point of the curve (1):

$$y = k/e \qquad \textbf{(1)}$$

Related to that, the saturation value is represented as a value in the solution of the Gompertz model equation (2) and it means the amount maximum of certificates that may be issued (Cabecinhas *et al.*, 2020).

$$y(t) = a.e^{-e^{[-k.(t-t_c)]}} \qquad \textbf{(2)}$$

RESULTS

The updated forecasting model established to predict the evolution of the ISO 22000 certification in Europe was built by using the OriginPro® software. Good fitting of data was evidenced in the curve which was fitted to the raw data from Table 1. The updated statistic parameters are reported in Table 2.

Table 2 – Updated parameters and statistics for the Gompertz fitting of European data.

Curve parameters	**Europe**
a	*10,565*
xc	*1.6307*
k	*0.3941*
R^2	*0.9456*

Based on available ISO 22000 European data, Figure 1 depicts the updated graphical representation of the forecasting model with additional number of issued certificates from the years 2019 and 2020. In line with the findings of Granja *et al.* (2021), both forecasting models evidence similar behavior which indicates that Europe is positioned in the stationary phase.

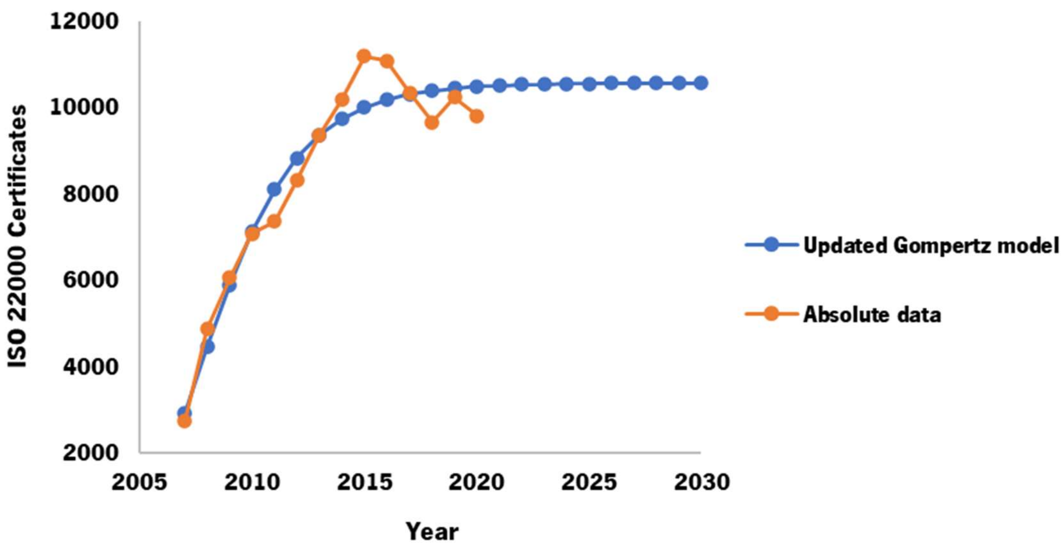

Figure 1 – Updated Gompertz curve (Europe) based on available data.

Similar to the findings of the original study carried out by Granja *et al*. (2021), it is possible to state that the diffusion of ISO 22000 certification in Europe already reached the inflection point in 2008. According to this present study, that point represents an amount of 3884 issued certificates. The updated ISO 22000 dynamic of diffusion suggests that the saturation phase will be reached in 2040 with related to an amount of 10,565 certificates issued, approximately, which represents the maximum value of certifications predicted by the forecasting model.

Despite the new data added to the analysis, the results of ISO 22000 certification behavior in European countries data still include uncertainties. To overcome this lack of data, it is necessary to update the forecasting model with new data from the forthcoming years.

The proposed intervals by Granja *et al*. (2021) encompassing the dynamic of ISO 22000 diffusion based on ISO 9001 and ISO 14001 growth also were updated to comprise the new established growth curve. In line with the findings of the aforementioned original study, Figure 2 demonstrates in an empirically way that the process of diffusion may be similar between the forecasting model based on available real data and the forecasting model with extrapolated data based on ISO 14001 growth.

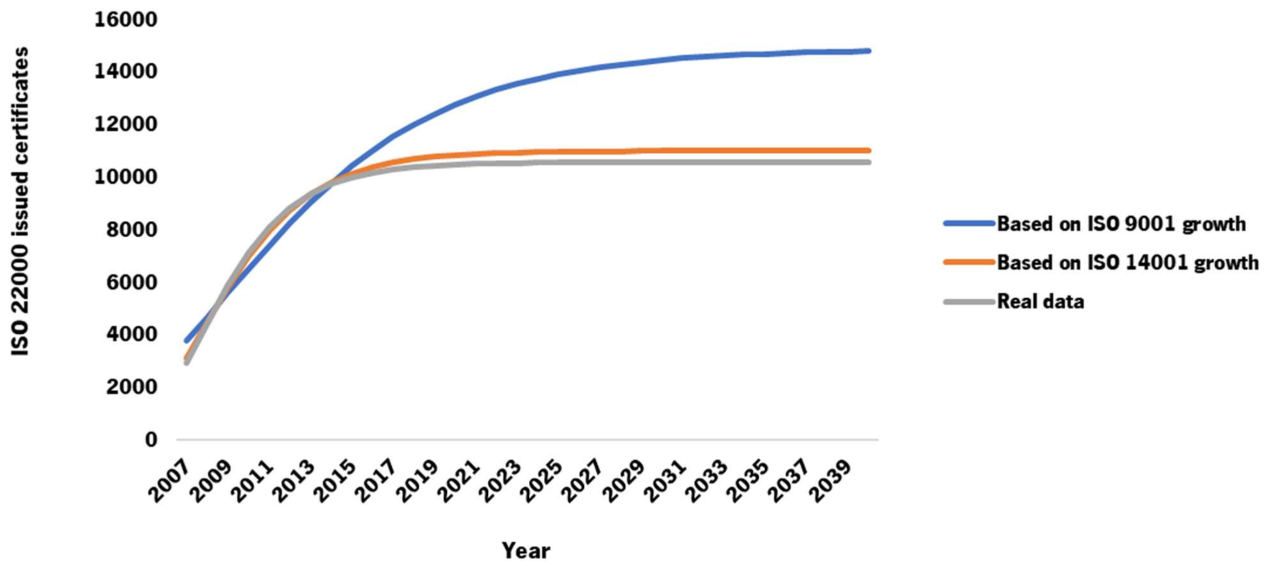

Figure 2 – Suggested intervals by Granja *et al*. (2021) to compare ISO 22000 certification in Europe updated with additional data from more recent years.

It suggests that ISO 22000 certification is affected by the role of cultural similarity, as is ISO 14001 (Albuquerque *et al*., 2007). The identified behavior may be related to the powered influence of stakeholders, communities, and authorities which comprise the main drivers of the ISO 22000 implementation. In spite of the different variables that are involved in the implementation process of standards (Rodriguez-Arnaldo and Martinez-Lorente, 2020), it is very clear to evidence the power of several international standards and regulations that impact and head the global agriculture and its international food trade (Herzfeld *et al*., 2011).

CONCLUSIONS

This study aimed at updating the original study carried out by Granja *et al*. (2021) by means of the diffusion of ISO 22000 certification in Europe encompassing some additional data from more recent years (2019 and 2020).

The presented findings confirm not only the current phase in which the European ISO 22000 certification is positioned (stationary phase), but also confirm that the inflection point of the established forecasting model has already been reached in 2008.

Considering the new growth curve of ISO 22000 diffusion in Europe, similarities were also confirmed between the updated forecasting model based on available real data and the forecasting model with extrapolated data based on ISO 14001 growth. Just like in the dynamic of ISO 14001 diffusion, the huge influence of required regulations and international standards in the international food trade may support the effect of the cultural similarity in the dynamic of ISO 22000 certification in Europe.

This present study reiterates the necessity of carrying out other studies to comprise the analysis of important variables and drivers that impact the dynamic of ISO 22000 certification in Europe for a better understanding of its diffusion process.

REFERENCES

Albuquerque, P., Broonenberg., B. and Cobertt, C. (2007), "A spatiotemporal analysis of the global diffusion of ISO 9000 and ISO 14000 certification", *Management Science*, Vol. 53 No. 3, pp.451-468. DOI: 10.1287/mnsc.1060.0633.

Alonso-Almeida, M.del M., Marimón, F. and Bernardo, M. (2013), "Diffusion of quality standards in the hospitality sector", *International Journal of Operations & Production Management*, Vol. 33 No. 5, pp.504-527. DOI: 10.1108/01443571311322706.

Berny, J. (1994), "New concepts and applications in growth phenomena", *Journal of Applied Statistics*, Vol. 21 No. 3, pp.161-189. DOI: 10.1080/757583654.

Bonanno, A., Busch, L., Friedland, W.H., Gouveia, L. and Mingione, E. (1994), "Introduction", Bonanno, A., Busch, L., Fried-land, W.H., Gouveia, L., & Mingione, E. (Eds.), From *Columbus to ConAgra: The Globalization of Agriculture and Food*. University Press of Kansas, Lawrence, KS, pp.1-28.

Cabecinhas, M., Domingues, P., Sampaio, P., Bernardo, M., Franceschini, F., Galetto, M. and HernandezVivanco, A. (2018), "Integrated management systems diffusion models in South European countries", *International Journal of Quality & Reliability Management*, Vol. 35 No. 10, pp.2289-2303. DOI: 10.1108/IJQRM-03-2017-0044.

Cabecinhas, M., Domingues, P., Sampaio, P. and Arezes, P. (2020), "Diffusion, drivers and trends on integrated management systems Evolution among Portuguese companies", *International Journal of Occupational and Environmental Safety*, Vol. 4 No. 1, pp.15-36. DOI: 10.24840/2184-0954_004.001.0002.

Chen, Y. and Liu, E. (2009), The diffusion of ISO 9000 certification in China: A trend analysis based on Grey Verhulst model, in *International Conference on Information Management 2009*, proceedings of the Innovation Management and Industrial Engineering, United States, pp.223-226. DOI: 10.1109/ICIII.2009.61.

Clougherty, J. A. and Grajek, M. (2014), "International standards and international trade: Empirical evidence from ISO 9000 diffusion", *International Journal of Industrial Organization*, Vol. 36, pp.70-82. DOI: 10.1016/j.ijindorg.2013.07.005.

Corbett, C.J. and Kirsch, D. A. (2001), "International diffusion of ISO 14000 certification", *Production and Operations Management*, Vol. 10 No. 3, pp.327-342. DOI: 10.1111/j.1937-5956.2001.tb00378.

Franceschini, F., Galetto, M. and Gianni, G. (2004), "A new forecasting model for diffusion of ISO 9000 standard certifications in European countries", *International Journal of Quality & Reliability Management*, Vol. 21 No. 1, pp.32-50. DOI: 10.1108/02656710410511687.

Franceschini, F., Galetto, M. and Cecconi, P. (2006), "A worldwide analysis of ISO 9000 standard diffusion - Considerations and future development", *Benchmarking: An International Journal*, Vol. 13 No. 4, pp.523-541. DOI: 10.1108/14635770610676326.

Franceschini, F., Galetto, M., Maisano, D. and Mastrogiacomo, L. (2010), "Clustering of European countries based on ISO 9000 certification diffusion", *International Journal of Quality &Reliability Management*, Vol. 27 No. 5, pp.558-575. DOI: 10.1108/02656711011043535.

Gil, L., Ruiz, P, Escrivá, L., Font, G. and Manyes, L. (2017), "A decade of Food Safety Management System based on ISO 22000: A global overview". *Rev. Toxicol*, Vol. 34 No. 2, pp.84-93.

Granja, N., Domingues, P., Cabecinhas, M., Zimon, D. and Sampaio, P. (2021), "ISO 22000 certification: Diffusion in Europe", *Resources*, Vol. 10 No. 100, pp. 17. DOI: 10.3390/resources10100100.

Havinga, T. (2013), "Food retailers as drivers for food safety standards", in Havinga, T., Hoevenaars, J., & Böcker, A. (Ed. s), Nijmegen sociology of law working papers series 2013/03, *SSRN Electronic Journal*. Radboud University Nijmegen, The Netherlands, pp.1-17.

Herzfeld, T., Drescher, L. and Grebitus, C. (2011), "Cross-national adoption of private food quality standards", *Food Policy*, Vol. 36 No. 3, pp.401-411. DOI: 10.1016/j.foodpol.2011.03.006.

Hikichi, S., Salgado, E. and Beijo, L. (2016), "Characterization of dissemination of ISO 14001 in countries and economic sectors in the Americas", *Journal of Environmental Planning and Management*. DOI: 10.1080/09640568.2016.1240070.

ISO 22000 Survey (2017), "The ISO Survey of Management System Standard certifications – ISO 22000 - data *per* country - 2007 to 2017", available at: https://www.iso.org/the-iso-survey.html (Accessed 19 May 2020).

ISO Survey (2018 to 2020), “The ISO Survey of Management System Standard certifications”, available at: https://www.iso.org/the-iso-survey.html (Accessed 19 May 2020).
Marimón, F., Heras, I. and Casadesús, M. (2008), “ISO 9001 and ISO 14001 diffusion - The case of Spain and Serbia”, In Proceedings of *Quality Festival 2008 proceedings of the 2nd International Quality Conference*, Kragujevac, pp.13-15.

Marimón, F., Heras, I. and Casadesús, M. (2009), “ISO 9000 and ISO 14000 standards: A projection model for the decline phase”, *Total Quality Management and Business Excellence*, Vol. 20 No. 1, pp.1-21. DOI: 10.1080/14783360802614257.

Mastrogiacomo, L., Carrozza, A., Maisano, D. A. and Franceschini, F. (2020), “Is ‘post-decline’ the next phase of the diffusion of ISO 9001 certifications? New empirical evidence from European countries”, *Total Quality Management & Business Excellence*, Vol. 32 No 12, pp.1384-1403. DOI: 10.1080/14783363.2020.1724508.

Meade, N. and Islam, T. (1998), “Technological forecasting - model selection, model stability, and combining models”, *Management Science*, Vol. 44 No. 8, pp.1115-1130. DOI: 10.1287/mnsc.44.8.1115.

Meade, N. and Islam, T. (2006), “Modelling and forecasting the diffusion of innovation – A 25-year review”, *International Journal of Forecasting*, Vol. 22, pp.519-545. DOI: 10.1016/j.ijforecast.2006.01.005.

Rodriguez-Arnaldo, O. and Martínez-Lorente, A. (2020), "What determinants influence the diffusion of ISO 9001 by countries?", *TQM Journal*, Vol. 33 No. 1, pp.233-246. DOI: 10.1108/TQM-03-2020-0055.

Salgado, E., Beijo, L., Sampaio, P., Mello, C. and Saraiva, P. (2015), “ISO 9001 certification in the American continent: A statistical analysis and modelling”, *International Journal of Production Research*, pp.1-18. DOI: 10.1080/00207543.2015.1109719.

Sampaio, P., Saraiva, P. and Guimarães, R. (2011), "ISO 9001 certification forecasting models", *International Journal of Quality and Reliability Management*, Vol. 28 No. 1, pp.5-26. DOI: 10.1108/02656711111097526.

Saraiva, P. and Duarte, B. (2003), "ISO 9000: some statistical results for a worldwide phenomenon", *Total Quality Management and Business Excellence*, Vol. 14 No. 10, pp.1169-1178. DOI: 10.1080/1478336032000107726.

To, W. and Lee, P. (2014), “Diffusion of ISO 14001 environmental management system: Global, regional and country-level analyses”, *Journal of Cleaner Production*, Vol. 66, pp.489-498. DOI: 10.1016/j.jclepro.2013.11.076.

Winsor, C. (1932), “The Gompertz curve as a growth curve”. Proceedings of the *National Academy of Sciences*, Vol. 18 No. 1, pp.1-8. DOI: 10.1073/pnas.18.1.1.

Are Lean, World Class Manufacturing and Industry 4.0 are related?

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Purpose: The purpose of this research is to present the relationships between the Lean Manufacturing methodology, the World-Class Manufacturing method and the practices of industry 4.0, showing how these actors have been discussed in literature, mainly in terms of gains and improvements for organizations.

Design/methodology/approach: The search strategy was extracting data from Web of Science and Scopus databases using the following keywords: “lean”, “lean production”, “lean manufacturing”, “WCM”, “world-class manufacturing”, “world class business” and “industry 4.0”. No restrictions of subject area were defined. For data analysis, bibliometric analysis was carried out using VOSviewer (version 1.6.9) and NetDraw (version 2.158) software.

Findings: This review reveals that studies related to Industry 4.0, World-Class Manufacturing, lean and Industry 4.0 and structured processes have the highest number of publications. Papers that bring the link between Lean and World-Class Manufacturing, and World-Class Manufacturing and Industry 4.0, are few, and 92% of them were published from 2018 onwards. There are no publications carried out on the three proposed topics as a set: Lean, World-Class Manufacturing and Industry practices 4.0. In the network analyses, three keyword clusters was found: technology, manufacturing and strategy.

Originality: There is no significant evidence in the literature that proves that the intense use of technologies associated with World-Class Manufacturing is related to greater efficiency in processes.

Keywords: Bibliometric analysis, World-Class Manufacturing, Industry 4.0 practices, Operations management.

Paper type: Literature Review

INTRODUTION

Faced with the fierce competition in the business, organizations - whether manufacturing and/or service - seek alternatives that help them overcome difficulties and continually improve the performance and quality of their processes. Production methods such as World-Class manufacturing, digital transformation based on industry 4.0 practices and the avant-garde Lean methodology production model, that when combined would promote positive results for organizations.

Implementing Lean manufacturing methodologies supports to improve the processes by eliminating non-value-added activities across supply chain and then attaining operational efficiency (Bajad, 2022). On the other hand, the World-Class Manufacturing surged as alternative to Lean and this approach focused mostly on cost and quality, it aims attention at zero-waste and continuous improvement of processes by engaging all employees. So, this helps organizations to achieve a global manufacturing performance, and consequently, remaining competitive (Chiarini and Vagnoni, 2015; Terra, Berssaneti and Quintanilha, 2021). Also, Industry 4.0 allows creating a "interconnected environment" where organizations can answer quickly, in real time and in a more effective way to changes using digital technologies (D'Orazio, Messina and Schiraldi, 2020). Therefore, extracting the best of each practice will help organizations to enable a sustainable manufacturing in order of operational and financial success.

This study aims to explore the relationships between the Lean Manufacturing, the World-Class Manufacturing and industry 4.0 in current literature, by showing how these actors have been discussed in literature, mainly in terms of gains and improvements for organizations. Therefore, the question to be answered by this paper is "are Lean Manufacturing, the World-Class Manufacturing and Industry 4.0 related to each other? What are major achievements from this synergy? And what are strategies to accomplish better results from each themes?".

To answer the proposed question, this paper conducted a review search, which is structured in four sections. Section 1 briefly introduces the subject that will be discussed. Section 2 describes the research methodology used in this study. Section 3 presents the main findings covered throughout paper analysis. Lastly, Section 4 summarises the discussions and shows limitation of study.

RESEARCH METODOLOGHY

This study is a bibliometric review in which has done a quantitative and qualitative analysis of papers. This type of analysis allows the evolution of the theme over the years, as well as highlighting the most cited publications and the main authors. Araújo, 2006 states that the bibliometrics analysis focus on usage of quantitative methods, performing objective estimates about scientific production.

The Scopus database was used as a reference for the collection of bibliometric information, due to the academic relevance that this database has. All papers that proved to be relevant and were found in the Web of Science database were also searched in the Scopus database and inserted in the bibliometric database.

To survey the database, searches were performed using the following search strings: “Lean”, “Lean production”, “Lean manufacturing”, “WCM”, “World-Class manufacturing”, “World Class Business” and “Industry 4.0”. These included terms were searched individually, and combining in pairs and trios, connected by the Boolean connector AND, which resulted in 42 combinations of searches. Only papers published in journals or conference proceedings until February 2022 were considered. No other filters were defined to extract papers. These articles were scanned by titles and abstracts and a final sample of 167 papers were assigned as relevant for the subsequent analyses. The sampling papers were analysed individually, allowing for a more in-depth study on the topic.

The first analyses realized throughout sampling articles were based on Bradford's 1934 dispersion law – which purpose to organize a set of documents in a descending manner, according to the number of citations (Araújo, 2006). It shows that only 29 papers, which have 100 or more citations, represent 90% of the total citations related to sample. These articles are displayed in Table 1. However, it is noteworthy that the analysis of the networks considered the complete sample, that is, 167 papers.

Table 1 – Most sampling articles cited

Paper	Authors	Year	Citation	Source
Dynamic capabilities and strategic management	David J. Teece; Gary Pisano; Amy Shuen	1997	15912	Strategic Management Journal
Dynamic capabilities: What are they?	Kathleen M. Eisenhardt and Jeffrey A. Martin	2000	7881	Strategic Management Journal
Opportunities of Sustainable Manufacturing in Industry 4.0	T. Stock and G. Seliger	2016	865	Procedia CIRP
Generalization in quantitative and qualitative research: Myths and strategies	Denise F. Polit and Cheryl Tatano Beck	2010	554	International Journal of Nursing Studies
Contingency research in operations management practices	Rui Sousa and Christopher A. Voss	2008	554	Journal of Operations Management
The expected contribution of Industry 4.0 technologies for industrial performance	Lucas Santos Dalenogarea, Guilherme Brittes Beniteza, Néstor Fabián Ayalab and Alejandro Germán Franka	2018	497	International Journal of Production Economics
Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives	Sachin S. Kamblea, Angappa Gunasekaranb and Shradha A. Gawankaraa	2018	431	Process Safety and Environmental Protection

The future of manufacturing industry: a strategic roadmap toward Industry 4.0	Morteza Ghobakhloo	2018	422	Journal of Manufacturing Technology Management
Industry 4.0 implies lean manufacturing: Research activities in industry 4.0 function as enablers for lean manufacturing	Adam Sanders, Chola Elangeswaran and Jens Wulfsberg	2016	381	Journal of Industrial Engineering and Management
Human resource management and employee well-being: towards a new analytic framework	David E. Guest	2017	348	Human Resource Management Journal
Successful lean implementation: Organizational culture and soft lean practices	Thomas Bortolotti, StefaniaBoscari and PamelaDanese	2015	323	International Journal of Production Economics
When titans meet – Can industry 4.0 revolutionise the environmentally-sustainable manufacturing wave? The role of critical success factors	Ana Beatriz Lopes de Sousa Jabboura, Charbel Jose Chiappetta Jabboura, Cyril Foropona and Moacir Godinho Filho	2018	313	Technological Forecasting and Social Change
Holistic Approach for Human Resource Management in Industry 4.0	Fabian Hecklaua, Mila Galeitzkea, Sebastian Flachsa and Holger Kohl	2016	295	Procedia CIRP
Ways of constructing research questions: Gap-spotting or problematization?	Jörgen Sandberg and Mats Alvesson	2011	288	Organization
Tangible Industry 4.0: A Scenario-Based Approach to Learning for the Future of Production	Selim Erola, Andreas Jägera, Philipp Holda, Karl Otta and Wilfried Sihna	2016	271	Procedia CIRP
Combining qualitative and quantitative research within mixed method research designs: A methodological review	Ulrika O¨stlund, Lisa Kidd, Yvonne Wengstro¨mc and Neneh Rowa-Dewar	2011	267	International Journal of Nursing Studies
Deploying Fog Computing in Industrial Internet of Things and Industry 4.0	Mohammad Aazam, Sherali Zeadally and Khaled A. Harras	2018	259	IEEE Transactions on Industrial Informatics
Towards Lean Production in Industry 4.0	Beata Mrugalska and Magdalena K. Wyrwicka	2017	242	Procedia Engineering
Exploring Industry 4.0 technologies to enable circular economy practices in a manufacturing context: A business model proposal	Daniel Luiz Mattos Nascimento, Viviam Alencastro, Osvaldo Luiz Gonçalves Quelhas, Rodrigo Goyannes Gusmão Caiado, Jose Arturo Garza-Reyes, Luis	2019	231	Journal of Manufacturing Technology Management

	Rocha-Lona and Guilherme Tortorella,			
Research methods and organization studies	Alan Bryman	2009	212	Research Methods and Organization Studies
The service revolution and the transformation of marketing science	Roland T. Rust and Ming-Hui Huang	2014	209	Marketing Science
The impact of big data on world-class sustainable manufacturing	Rameshwar Dubey, Angappa Gunasekaran, Stephen J. Childe, Samuel Fosso Wamba and Thanos Papadopoulos	2016	194	International Journal of Advanced Manufacturing Technology
Industry 4.0 – Are we ready?	Ślusarczyk B.	2018	174	Polish Journal of Management Studies
SDMSim: A manufacturing service supply–demand matching simulator under cloud environment	Fei Tao, Jiangfeng Cheng, Ying Cheng, Shixin Gu, Tianyu Zheng and Hao Yang	2017	156	Robotics and Computer-Integrated Manufacturing
Factors influencing employee perceptions in lean transformations	David Losonci, Krisztina Demeter and Istvan Jenei	2011	135	International Journal of Production Economics
Towards a lean automation interface for workstations	Dennis Kolberg, Joshua Knobloch and Detlef Zühlke	2017	126	International Journal of Production Research
Industry 4.0 and lean management: a proposed integration model and research propositions	Michael Sony	2018	118	Production and Manufacturing Research
Engineering Methods and Tools for Cyber-Physical Automation Systems	Robert Harrison, Daniel Vera and Bilal Ahmad	2016	108	Proceedings of the IEEE

The next analyses were performed into VOSviewer software, version 1.6.9, in order to evaluate the analysis of contents from relationship networks built between articles into sample.

BIBLIOMETRIC ANALYSIS

Firstly, analysing the sample of 167 papers, it shows that no journal stands out with many publications. Thus, it means that relationship between the main three topics of study – World-Class Manufacturing, Lean Manufacturing and Industry 4.0 – has not yet been explored in depth. Furthermore, it highlights the existing gap in literature, which needs to be exploited by future studies.

Consecutively, it was performance an assessment of 167 papers' content in order to raise the most themes mentioned by them. In Figure 1, these main themes are summarized and it considers evolution of a subject throughout years and representativeness of each subject.

Main themes covered in sample \ Ano	1984	1992	1994	1996	1997	1999	2000	2001	2003	2005	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	Representativeness of the themes
Multi-Criteria Decision Analysis					1										1											1,21%
BPM			1					1						1				1			1				1	3,64%
Industry 4.0																				11	4	17	1	1		20,61%
Lean			1												1			1			2	1	7	4	7	14,55%
Lean and Agile																					1					0,61%
Lean and Industry 4.0							1												1	1	4	5	4	1	8	15,15%
Lean and IT																					1					0,61%
Lean and manufacturing																					4		1	1		3,64%
Lean and six sigma																					1					0,61%
Lean and VSM																					1					0,61%
Lean and WCM				1																		1	3	3		4,85%
Manufacturing					1	1						1			1	1					2					4,24%
Structured process					1								1		1	1	1	3	1	4	1	3				10,30%
Structured process and unstructured process																						1				0,61%
Semi-Structured process	1				1				1								1									2,42%
WCM		1	1	2	2		1		1	1	2	2							1	2	2	2	1	1		13,33%
WCM and Industry 4.0																						1	2	1	1	3,03%

Figure 1 – Themes covered by papers throughout years (1984-2021).

This Figure 1 shows that Industry 4.0 was the most theme discussed by authors into 34 papers, following by Lean and Industry 4.0 (25 papers), Lean (24 papers) and WCM (22 papers). In other words, the relationship between Lean and Industry 4.0 practices has been largely explored in literature. Whereas papers that brought out the discussion of Lean and WCM (8 papers) and Industry 4.0 and WCM (5 papers) were not in large majority.

About the evolution of papers over the years, Figure 2 exhibits this trend. This graphic shows that number of publications had increased until 2018, with the main peak. From then on, there was a drop in the number of papers in the last 3 years, but starting to recover in 2021. In addition, it was observed that between 2016 and 2021 is the gold era regarding this theme if compared with previous years, due to aggressive competition imposed to organization, which has to look for alternatives such as World-Class Manufacturing, Industry 4.0 and Lean methodology to overcome those new challenges.

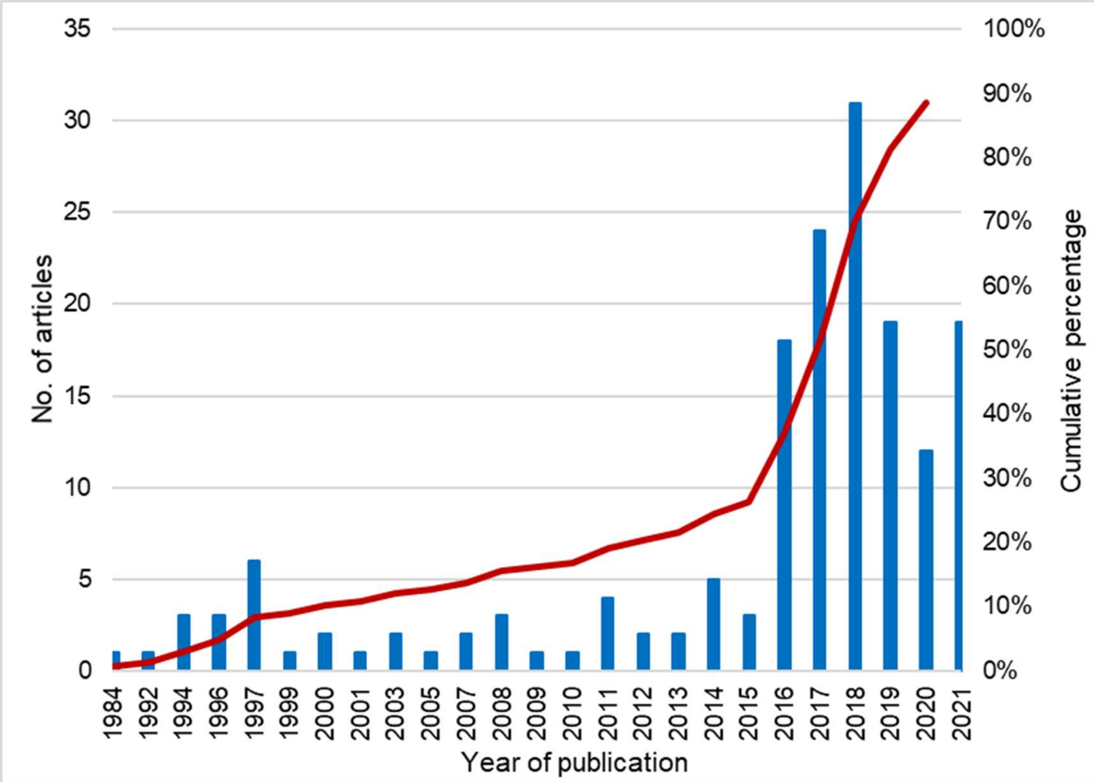

Figure 2 – Evolution of papers over years.

This study also examined the most cited papers of sample. The paper with the most citations was "Dynamic capabilities and strategic management" (Teece et al., 1997). It had 15,1912 citations, which corresponds to 46.6% of total number of citations in sample. This paper discussed about dynamic capabilities, i.e., continuous improvement, and how they influence the manufacturing processes and service environment. As WCM is directly influenced by continuous improvement processes, this paper has many ramifications and citations, thus it has been a relevant reference for the study of Lean methodologies and improvement processes.

The second most cited paper was "Dynamic capabilities: What are they?" (Eisenhardt and Martin, 2000). This paper has at least half of number of citations of previous most cited paper, with 7,881 which represents 23.1% of total number of citations. In this paper, the authors complemented the theories of Teece et al. (1997) and enlarged a greater understanding of the process of continuous improvement in manufacturing and service processes. In addition, they introduced – albeit superficially – about the work and human relationships in this process, triggering a set of factors that are decisive for the advancement of Lean methodologies and the WCM method in manufacturing processes.

The first and second papers, together, corresponded to 69.6% of total of sampling citation. The remaining 167 papers correspond to 30,4% of total citations. The third paper most cited was

"Opportunities of Sustainable Manufacturing in Industry 4.0" (Stock and Seliger, 2016), and it had 805 citations (2.5%).

Other analysis was about keywords used by author in sampling papers. It is important to highlight that the keywords lean management and lean were unified, throughout the paper, in the word lean, to simplify the analysis.

Figure 3 shows the occurrence of keywords. Most keywords emphasized by papers are "Lean" (45 papers), "Industry 4.0" (35 papers), "Internet of Things" (21 papers), WCM (20 papers). The other ones have less than 20 references. Based on most cited keywords, it observed that they are closed related with the theme discussed by this study – relationship between WCM, Industry 4.0 practices and Lean.

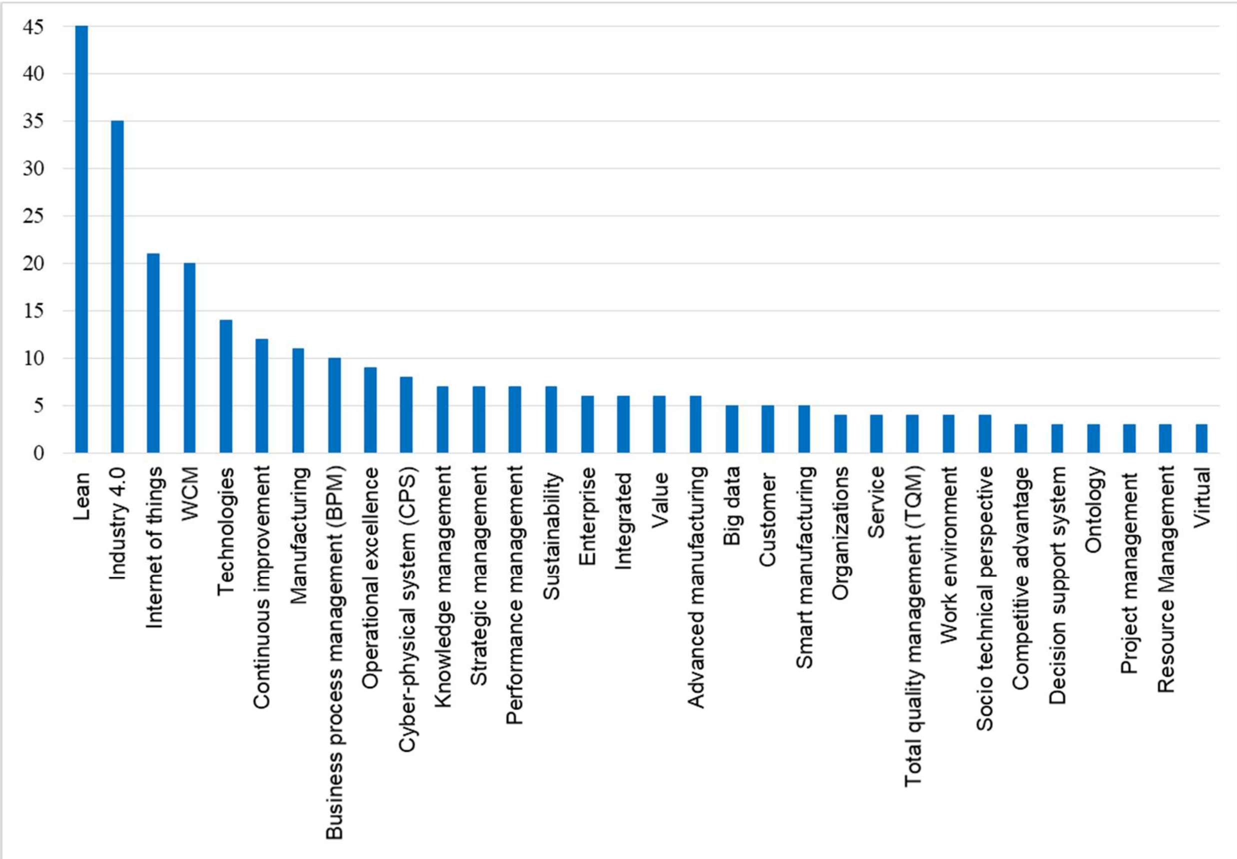

Figure 3 – Keywords occurrence.

NETWORKING ANALYSIS

The next analysis realized were networking analysis throughout co-occurrence of authors' keywords. The authors' keywords network map shows the relationship between the words used to search for papers and the frequency with which they occur. The proposed criterion for cutting was five occurrences, it means that keywords cited five times or more were considered to build the map.

Additionally, keywords that were not related to the study were excluded from the analysis. Figure 4 illustrates three well-defined cores that were formed based on relationship between co-occurrence of keywords; they are: i) concepts of manufacturing and production processes (orange); ii) lean and improvement processes (green) and iii) Industry 4.0 practices and technological processes (blue). Each of these topics will be discussed in the next paragraphs.

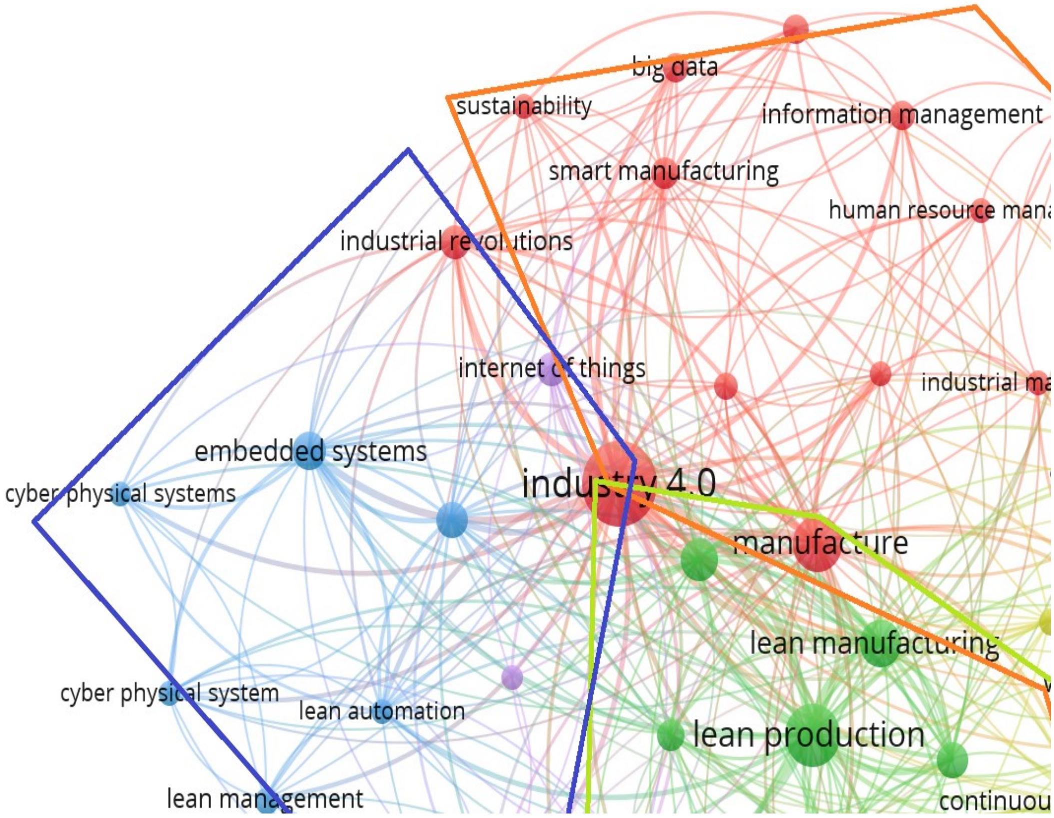

Figure 4 – Occurrence of Keywords network map.

Concepts of manufacturing and production processes (orange ring): World-Class Manufacturing also points in the direction of inefficiencies and reduction waste. Lee and Oakes (1996) declared that a new approach to manufacturing can support in waste removal and improvements of quality of products and services. This leads to a culture of quality that generates a proactive approach, with the involvement of team members, whose objective is to improve productivity, facilitate innovation processes and encourage workers to engage in self-development (Mróz, 2018). For this to run steadily, it is important to integrate available human and material resources (Mendes and Mattos, 2017), creating a sustainable cycle. Thus, the implementation of an organizational environment that facilitates the transition of organizations to world-class performance (Satolo et al., 2018), associated with a strong digital component, generating opportunities to innovate in products, processes and goals of innovation (Furlan and Vinelli, 2018).

Lean and improvement processes (green ring): The keyword "Lean" has a strong relationship with manufacturing processes. The connections between Lean and the concepts of operational excellence led to continuous improvement, whose objective has been focused on elimination of wastes. Barker (1994) stated that waste can be considered as a potential opportunity to be explored, since it exists throughout the value addition chain, thus eliminating those inefficiencies could help to greatly improve the performance of the organization. Organizations have increasingly understood that the continuous assessment of organizational performance is necessary to remain competitive (Sangwa and Sangwan, 2018), reducing economic vulnerability, making organizations more resilient in their operations, in such a way that the relevant strategies to production efficiency and capacity are fundamental (Lotfi and Saghiri, 2018). This makes current business models require a modeling of their processes for later use of technologies (Azevedo, 2017). However, it requires more robust projects with continuous improvement practices that are constantly used, since the technological model of Industry 4.0 practices requires constant updates (Rossini et al., 2019), both in manufacturing processes and associated services.

Industry 4.0 practices and technological processes (blue ring): The relationship between Lean and Industry 4.0 practices is aimed at improving productivity and flexibility (Buer et al., 2018; Sordan et al., 2021), reducing complexity and focusing on tasks that add value (Kolberg et al., 2018). The challenge is to allow a similar level of evolution, both at the operational and managerial levels, aligned with the possibility of an integrated evolution (Villalba-diez et al., 2018). Ciano et al. (2021) proposed a framework to help organizations to reach a better synergy between those two practices in order to improve their operations by showing many tools that if works together can promote an effective gain, like autonomous robots and Internet of Things working with SMED and standardised work. In practice, the stimulus to the continuous use of technologies associated with Lean is in the integration between the technologies and the expected results for the investment made, i.e., it is in allowing greater flexibility to the processes (Ciano et al., 2021). However, the connections between productive efficiency, represented here by WCM and have a secondary connection with technological processes, as shown in Figure 5.

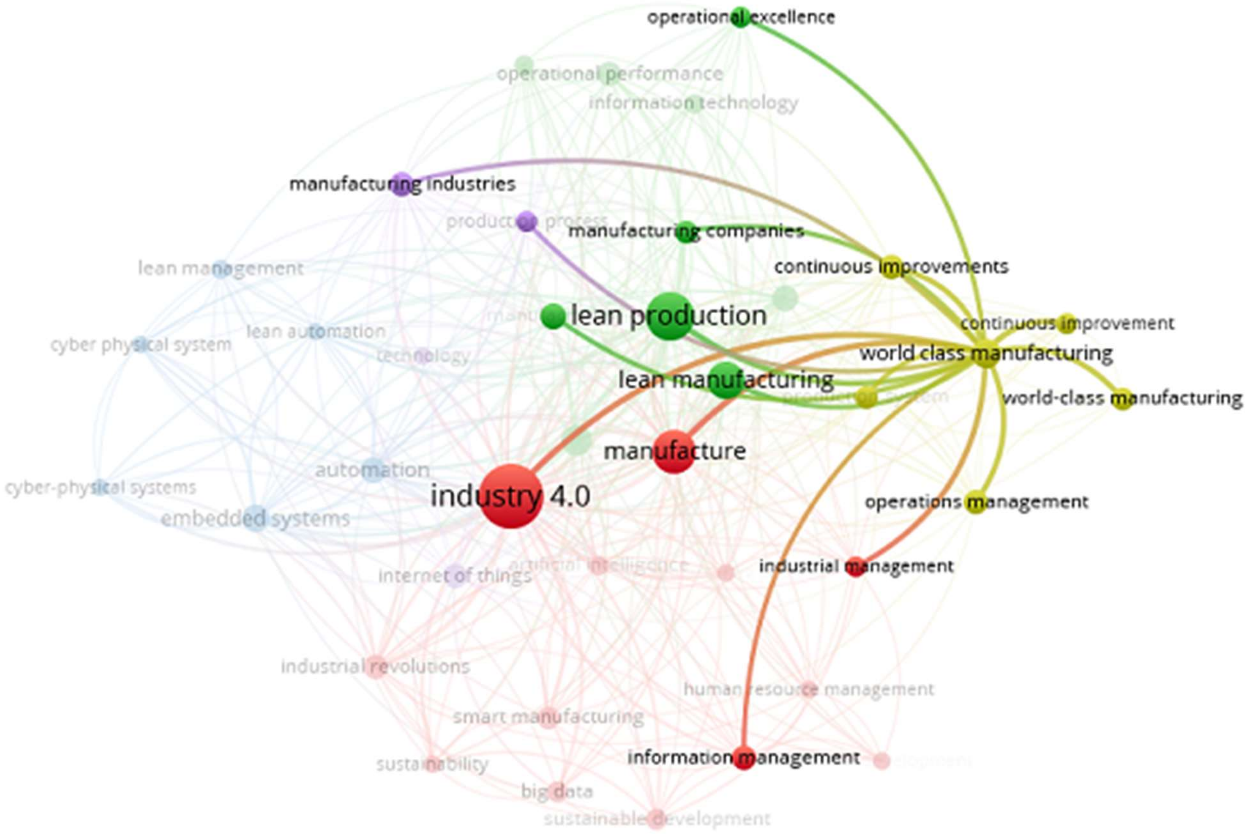

Figure 5 – World-Class manufacturing keywords occurrences network map.

Oliveira et al. (2016) stated that organizations that want to build long-term competitive advantages seek to develop World-Class Manufacturing practices and, at the same time, remain flexible enough to maintain themselves. Thus, the need for integration between the efficiency shown by the WCM and the flexibility in the processes, shown by the practices of Industry 4.0 practices, stands out.

Another relevant keyword was “information management”, showing the need to maintain reliable databases in manufacturing processes: without information there is no sustainable improvement process.

Finally, this study examines the relationship of co-authorship. The formation of the most cited authors’ network had been built considering those who were cited at least hundred times. Figure 6 shows the network of relationships among the major cited authors of sample. However, the analysis of the paper considers the most cited authors, as this is the list available in the network analysis program.

Teece et al. (1997) were the most cited authors in the database and they debated about dynamic capabilities, strategies and how they influence processes. The same authors argued that the strategic theory is full of analyses that support and safeguard the combinations between technological competences, product and process development, technology transfer, intellectual property, manufacturing and human resources and are linked to a greater competitive advantage, supported by in different processes.

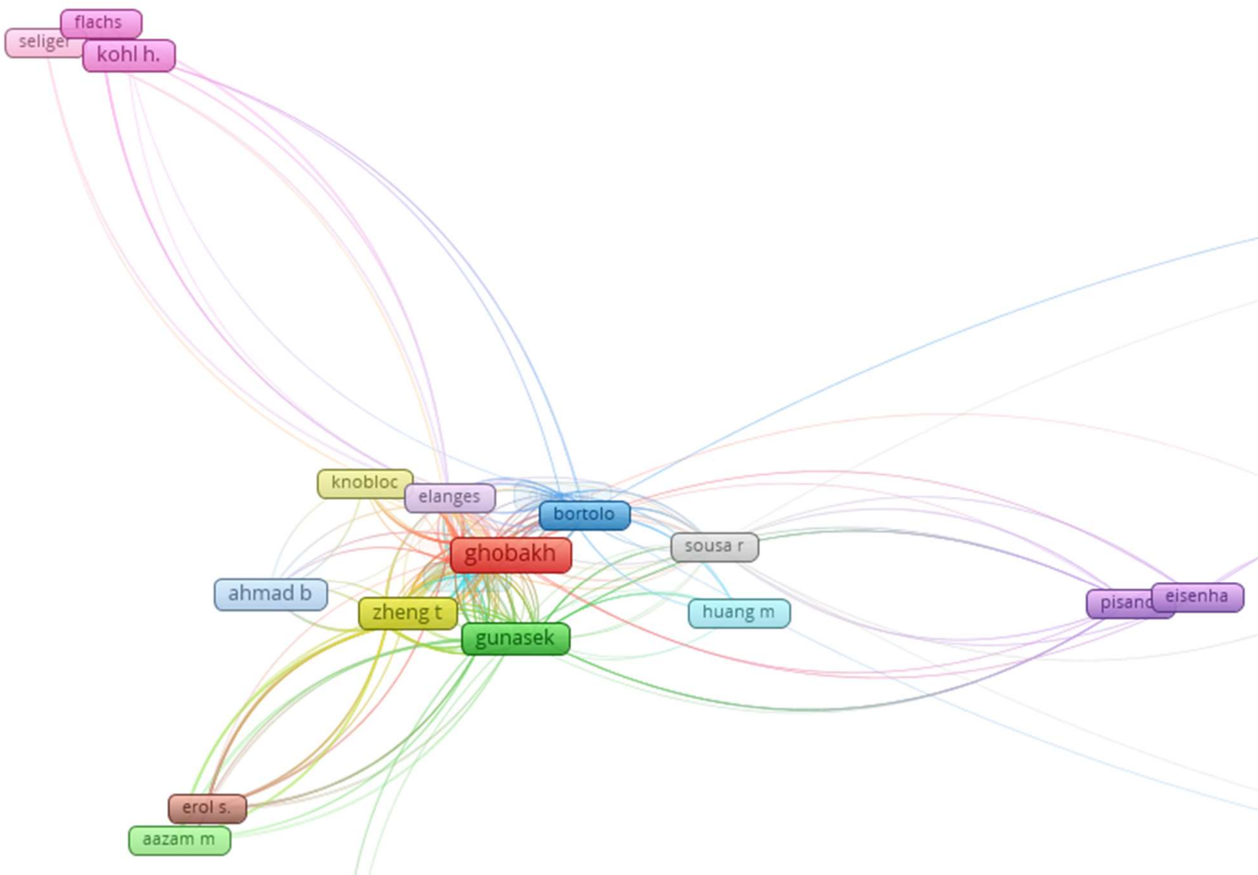

Figure 6 – Most cited author's network.

Eisenhardt and Martin (2000) also had a high number of citations. They asserted that the organizational processes associated with the organizations' strategy are capable of creating value in markets with dynamic characteristics, where the structure of the industry is undefined. They claimed that processes are generally simple, experimental and unstable and that they rely on new knowledge created quickly, iteratively, to produce adaptable results. This makes manufacturing processes more flexible and reconfigurable, as well as requiring a dynamic value stream mapping (Tran et al., 2021).

Eisenhardt and Martin (2000) had worked on dynamic capabilities, processes and strategy, which shows their strong connection with the topics addressed and may explain the high number of citations. Considering the strategic factor, Industry 4.0 practices play an important role. Stock and Seliger (2016) stated that creating value in an organization that adopts the principles of Industry 4.0 practices offers immense opportunities for sustainable manufacturing, interconnecting the entire value chain, offering new opportunities for carrying out continuous development cycles.

It is noted that the dynamic approaches have a strong relationship with the different topics covered. From these perspectives - strategy and technological competencies, value creation and link between manufacturing and strategic management, there is a direction towards more sustainable and efficient manufacturing process practices in decision making (Dubey et al., 2016). The entire integration of the different actors needs to be recreated, which implies in a horizontal and vertical integration, from end to end (Chiarini and Kumar, 2021).

The practices of Industry 4.0, Lean methodology and World-Class Manufacturing method fit together. Industry 4.0 practices correspond to technological direction and rapid process development, Lean methodology corresponds to the effectiveness and efficiency of these processes and World-Class Manufacturing method directs to the strategic aspect, with a strong application of a tool orientated to human side, such as Kaizen, which is seen as more focused on people (Anosike et al., 2021). Plus, Tran, Ruppert and Abonyi (2021) added that those practices beyond supporting the system optimization, they are a "stress-free" way to manage, so managers can focus on other activities to continuous improvement of systems.

Thus, horizontal integration occurs, characterized by a value creation network, providing a new and innovative business environment and, therefore, leading to a change in markets (Stock and Seliger, 2016), which is also capable of empowering organizations. faster and more flexible responses, considering the complexity of the processes (Mrugalska and Wyrwicka, 2017).

Ghobakhloo (2018) affirm that a blend of ideas, since it encompasses the practices of Industry 4.0 to an integrative system of value creation, composed of process design principles and technological trends. Vlachos et al. (2021) corroborated to this analysis, as they claimed that Lean, associated with processes, has significant managerial implications, helping companies to integrate and focus on people, with the help of technologies that promote process efficiency.

Bortolotti et al. (2015) highlighted about complexity of using this innovative model for workers who have little aptitude for multidisciplinary work. Kolberg et al. (2017) pointed to the growth in the use of Lean associated with technological systems and the need for workers to perform different tasks. However, the effects of technology are only developed at a high level, without a deep and comprehensive analysis (Ciano et al., 2021).

Sanders et al. (2016) addressed the Lean environment in Industry 4.0 practices and the reluctance in the implementation of this new way of producing. In fact, companies are still looking for technological solutions to reduce costs and delivery times, especially if the benefits perceived by companies are related to efficiency gains; however, when companies put these technologies into practice, competence is consistently considered the most significant barrier (Zheng et al., 2021).

Organizations have used Lean concepts to optimize production and eliminate waste (Amjad et al., 2021). Improvements in the flow of information, decision making and productivity are highlighted, combining different actors (Anosike et al., 2021), one of the fundamental principles of the World-

Class Manufacturing. The complexity of the topic involves different scenarios, since it includes not only Lean, WCM and Industry 4.0 practices, but the strategic vision of the business and the way in which work relationships are taking place.

Ejsmont et al. (2020) stated that companies, in order to be competitive, constantly seek continuous increase in productivity, quality and level of services. With the development of the Industry 4.0 concept, organizations are more confident about the new advantages that such technologies allow for systems integration. Still, Sousa and Voss (2008) highlighted this complexity when considering operations management applied to activities that characterize the emergence of a new type of organization, which stands out in the environment in which it is inserted. This idea has a strong bearing on WCM, as it promises to make manufacturing processes more efficient (Santos et al., 2021). Moreover, the powerful combination of different digital principles and technologies accelerates waste identification and mitigation faster than traditional methods, causing solutions to be incorporated by all involved (Tran et al., 2021).

CRITICAL ANALYSIS

In the literature presented, the WCM brings together a set of manufacturing concepts that is related to different quality methods, whose objective is focused in the continuous improvement processes. The method points to the use of best management practices, with emphasis on cost analysis, integration of people, flexibility in processes, focus on efficiency, and technological innovation. However, reliability for Industry 4.0 practices still generate insecurity within organizations, since they are not fully developed and consolidate theme.

In order to help this organizational structure to work properly, the continued development of human resources is necessary, often neglected by top management, and the respective compensation for the suggested and implemented improvements, indicating an increase in the ability to apply tools aimed at continuous improvement, in search of best practices.

Organizations that are most successful with the application of WCM and lean are those that make extensive use of practices that connect people, such as training workers to multitask, partnering within supply chain, customer involvement, and continuous improvement, with technical and analytical tools.

The synergy between WCM and lean, as a relevant element for the reduction of waste, the dissemination of a culture of continuous improvement and the practices of Industry 4.0, as a driving force for the implementation of new technologies in the production process, point to greater transparency in indicators, resulting in organizations that guide their organizational models towards medium and long-term strategic management.

Additionally, about the technological aspects, this integration occurs in a more accentuated and dynamic way, strengthening the connections between WCM, lean and Industry 4.0 practices. These both actors are often used in same place. The difference is that the “consumption” of information becomes more dynamic and assertive, so that communication flows turn heavily intensive.

This integration can provide significant gains in production systems, attracting customers based on strategic issues, such as the high speed in providing a product, service or production on demand. In a more complex and innovative context, they are able to act and modify the environment that they are inserted, reacting to different situations and preventing the factory environment from bad weather or problems arising from a failed process.

However, despite the improvement in processes being increasingly apparent, there is still no significant evidence in the literature that proves that the intense use of technologies, associated with WCM, relate to a higher quality in the products and services offered to customers.

CONCLUSIONS

The present paper carried out an analysis about the relationship between Lean Manufacturing, WCM and Industry 4.0 practices in order to evaluate the main discussion and gains from this synergy. The literature brings together a set of manufacturing concepts that directs to relationships between different quality methods, whose objective is focused and continuous improvement in processes. These concepts pointed to the use of best management practices, with emphasis on the integration of people, flexibility in processes and technological innovation. The use of these techniques focuses on efficiency, through the reduction of operating costs and waste, with the same focus as Lean.

Industry 4.0 practices was the most theme discussed by authors, following by “Lean and Industry 4.0”, “Lean” and “WCM”; major keywords highlighted into papers are “Lean”, “Industry 4.0”, “Internet of Things”, WCM; and it seems to be a “golden era” from 2015 until now in discussing about methodologies that support the continuous improvement of organizations.

In addition, Figure 4 identified three keyword clusters: concepts of manufacturing and production processes, lean and improvement processes and Industry 4.0 practices and technological processes.

Concepts of manufacturing and production processes represents the relationships between production processes and the methods and practices used in manufacturing in search of better performance and efficiency. In this cluster, the relationships with the management of operations and the proximity of the best results with the use and application of WCM stand out. Figure 5 asserts this relationship and shows the strong influence of lean methodology on the WCM method, being the main vector in its development.

Industry 4.0 practices and technological processes represents themes related to technological innovations. This cluster shows the development of manufacturing through the use and integration of technologies and how they relate to the lean methodology, under the strong influence of continuous improvement processes. The integration with the WCM method and trends in the modernization of manufacturing and associated services stand out.

Lean and improvement processes represent the objectives for the application and use of WCM method and Lean methodology from the point of view of Industry 4.0 practices as a strategic factor for organizations. World-Class Manufacturing stands out with a strong interaction with Lean, but still maintains weak relationships with technology and Industry 4.0 practices, which demonstrates that there is a gap to be developed.

In the network of most cited authors, Teece et al. (1997) and Eisenhardt and Martin (2000) presente a large number of citations, thus they are the main references in studies involving continuous improvement. However, Ghobakhloo (2018), Figure 6, is relevant to the network since he assumes a role of linking different topics, and seeking to unify ideas around continuous improvement and technologies used.

While Teece et al. (1997) and Eisenhardt and Martin (2000) focused on developing theory on the subject, Ghobakhloo (2018) sought to unify the concepts more comprehensively, reaching different areas of knowledge. This paper shows a positive evolution as it begins the exploration between Industry 4.0 practices with manufacturing processes. However, it does not introduce into the WCM method.

Kassem and Staudacher (2021) highlighted the central role of competencies, the need for a specialized team to monitor the implementation of improvements, as well as a better formulation of the tool offerings to implement them.

However, the database papers do not show the connection between Lean, WCM and Industry 4.0 practices, making only occasional analysis, without investigate into the subject. Also, considering the WCM vector, no author scales its extent.

Additionally, studies could confirm that WCM does not require excess labor demand. It simply changes the way processes run, making them more efficient. As a result, the World-Class Manufacturing seeks to promote and disseminate the culture of continuous improvement, base of Lean, through the different operations developed by the organization, whose focus is directed towards the strategic vision and advanced technologies, based on Industry 4.0 practices.

This paper has some limitations: i) highlights the combination of string used to search the documents, and it was limited to two databases; ii) the subjectivity of each author in evaluating the sampling papers and reach a consensus; iii) number of papers studied considering the number of papers published, mainly about lean; iv) process ~~first method~~ to analyse the papers, throughout reading only the abstract and title as first filter.

Future research can explore the results raised in this study; considering another method to analyse the networks and papers. Even though presence of those limitations, they do not invalidate the findings of paper. This paper is relevant to operation management literature due to increase interesting of continuous improvement of organizations to remain competitive in market.

REFERENCES

Amjad, M.S., Rafique, M.Z. and Khan, M.A. (2021), "Leveraging Optimized and Cleaner Production through Industry 4.0", Sustainable Production and Consumption, Vol. 26, pp. 859-871..

Anosike, A., Alafropatis, K., Garza-Reyes, J.A., Kumar, A., Luthra, S. and Rocha-Lona, L. (2021), "Lean manufacturing and internet of things – A synergetic or antagonist relationship?", Computers in Industry, available at:https://doi.org/10.1016/j.compind.2021.103464.

Araújo, C.A. (2006), "Bibliometria: evolução história e questões atuais", Em Questão, Vol. 12 No. 1, pp. 11–32.

Bajad, M. (2022). Simplified and practical lean approach towards sustainable infrastructure. Innovative Infrastructure Solutions, Vol. 7 No. 3, available at:https://doi.org/10.1007/s41062-022-00797-w.

Bortolotti, T., Boscari, S. and Danese, P. (2015), "Successful lean implementation: Organizational culture and soft lean practices", International Journal of Production Economics, Vol. 160, pp. 182–201.

Barker, R.C. (1994), "Production Systems Without MRP: A Lean Time Based Design", International Journal Management Science, Vol. 22 No. 4, pp. 349–360.

Buer, S.-V., Strandhagen, J.O. and Chan, F.T.S. (2018), "The link between Industry 4.0 and lean manufacturing: mapping current research and establishing a research agenda", International Journal of Production Research, Vol. 56 No. 8, pp. 2924–2940.

Chiarini, A. and Vagnoni, E. (2015), "World-class manufacturing by fiat. comparison with toyota production system from a strategic management, management accounting, operations management and performance measurement dimension", International Journal of Production Research, Vol. 53 No. 2, pp. 590-606.

Ciano, M.P., Dallasega, P., Orzes, G. and Rossi, T (2021), "One-to-one relationships between Industry 4.0 technologies and Lean Production techniques: a multiple case study", International Journal of Production Research, Vol. 59 No. 5, pp.1386-1410.

D'Orazio L, Messina R, Schiraldi MM. Industry 4.0 and World Class Manufacturing Integration: 100 Technologies for a WCM-I4.0 (2020), Matrix. Applied Sciences, Vol. 10 No. 14:4942, available at https://doi.org/10.3390/app10144942.

Dubey, R., Gunasekaran, A., Childe, S.J., Wamba, S.F. and Papadopoulos, T. (2016), "The impact of big data on world-class sustainable manufacturing", International Journal Advanced Technology, Vol. 84, pp. 631–645.

Eisenhardt, K.M. and Martin, J.A. (2000), "Dynamic capabilities: What are they?", Strategic Management Journal, Vol. 21 No. 10/11, pp. 1105–1121.

Ejsmont, K., Gladysz, B., Corti, D., Castaño, F., Mohammed, W.M. and Martinez Lastra, J.L. (2020), "Towards 'Lean Industry 4.0′ – Current trends and future perspectives", edited by Foroudi, P.Cogent Business & Management, Vol. 7 No. 1, p. 1781995.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", Journal of Manufacturing Technology Management, Vol. 29 No. 6, pp. 910–936.

Kolberg, D., Knobloch, J. and Zühlke, D. (2017), "Towards a lean automation interface for workstations", International Journal of Production Research, Taylor & Francis, Vol. 55 No. 10, pp. 2845–2856.

Lee, G.L. and Oakes, I.K. (1996), "Templates for change with supply chain rationalization", International Journal of Operations & Production Management, Vol. 16 No. 2, pp. 197–209.

Mrugalska, B. and Wyrwicka, M.K. (2017), "Towards Lean Production in Industry 4 .0", Procedia Engineering, Vol. 182, pp. 466–473.

Oliveira, P. sergio G., Silva, D., Silva, L.F., Tecilia, M.C. and Llopes, M. dos S. (2016), "Proposition factor model of world class manufacturing in Brazilian enterprises", Independent Journal of Management & Production, Vol. 7 No. 2, pp. 488–502.

Sanders, A., Elangeswaran, C. and Wulfsberg, J. (2016), "Industry 4.0 Implies Lean Manufacturing: Research Activities in Industry 4.0 Function as Enablers for Lean Manufacturing", Journal of Industrial Emgineering and Management, Vol. 9 No. 3, pp. 811–833.

Santos, B.P., Enrique, D.V., Maciel, V.B.P., Lima, T.M., Charrua-Santos, F. and Walczak, R. (2021), “The synergic relationship between industry 4.0 and lean management: Best practices from the literature”, Management and Production Engineering Review, No. 1, pp. 94-107

Sordan, J.E., Oprime, P.C., Pimenta, M.L., Lombardi, F. and Chiabert, P. (2021), "Symbiotic relationship between robotics and Lean Manufacturing: a case study involving line balancing", The TQM Journal, Vol. ahead-of-print No. ahead-of-print, available at:https://doi.org/10.1108/TQM-03-2021-0073

Sousa, R. and Voss, C.A. (2008), “Contingency research in operations management practices”, Journals of Operations Management, Vol. 26, pp. 697–713.

Stock, T. and Seliger, G. (2016), “Opportunities of Sustainable Manufacturing in Industry 4.0”, Procedia CIRP, Elsevier B.V., Vol. 40, pp. 536–541.

Teece, D.J., Pisano, G. and Shuen, A. (1997), “Dynamic Capabilities and Strategic Management”, Strategic Management Journal, Vol. 18 No. 7, pp. 509–533.

Terra, J. D. R., Berssaneti, F. T., and Quintanilha, J. A. (2021)." Challenges and barriers to connecting world class manufacturing and continuous improvement processes to industry 4.0 paradigms", Engineering Management in Production and Services, Vol. 13 No. 4, pp.115-130.

Tran, T. -., Ruppert, T., and Abonyi, J. (2021). "Indoor positioning systems can revolutionise digital lean", Applied Sciences (Switzerland), Vol. 11 No. 11, available at:https://doi.org/10.3390/app11115291.

Villalba-diez, J., Rossner, M., Lay, M. and Ordieres-Meré, J. (2018), “Lean Dendrochronnology: Complexity Reduction by Representation of KPI Dynamics Looking at Strategic Organizational Design”, Management and Production Engineering Review, Vol. 9 No. 4, pp. 3–9.

Vlachos, I.P., Pascazzi, R.M., Zobolas, G., Repoussis, P. and Giannakis, M. (2021), “Lean manufacturing systems in the area of Industry 4.0: a lean automation plan of AGVs/IoT integration”, Production Planning and Control, available at:https://doi.org/10.1080/09537287.2021.1917720.

Zheng, T., Ardolino, M., Bacchetti, A. and Perona, M. (2021), “The road towards industry 4.0: a comparative study of the state-of-the-art in the Italian manufacturing industry”, Benchmarking, available at:https://doi.org/10.1108/BIJ-01-2021-0056.

Defect reduction using Lean Six Sigma and DMAIC

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ABSTRACT

Purpose - Competitive pressures forces companies to seek solutions to eliminate wastes while improve product quality. Lean Six Sigma has been considered one of the most effective approaches for business transformation. This article aims to present an empirical case study where Lean Six Sigma and DMAIC methodologies are applied to reduce defects in an auto parts manufacturer.

Design/methodology/approach - The study follows the DMAIC methodology to investigate the root causes of defects and offer the solutions to reduce them. Design of experiments and hypothesis testing were applied in a single case study with interviews in the DMAIC steps sequence.

Findings - The analysis carried pointed out the main defects in each of two manufacturing phases: die casting and machining. Mold temperature, metal temperature and second stage injection speed influenced the amount of defective die casting parts. On the other hand, the incidence of defects in machining process was affected by the fixation method. Solutions implemented reduced the defect incidence from a chronically high level to an acceptable one. The sigma level rose from 3.4 σ to 4σ sustainably.

Research limitations/implications - The study are limited to a single case study, without intention of generalizing the results to other types of industries.

Practical implications - This paper can be used for those who intend to use the same type of improvement methodologies.

Originality/value - This study describe in detail the entire process used in a structured improvement exercise.

Keywords: Defect reduction, Lean Six Sigma, DMAIC

Paper type: Case study

INTRODUCTION

Many organizations are committed to improving product quality and process performance in an attempt to achieve a set of bottom-line and strategic goals, including profitability, market share, and competitiveness (Daniyan *et al*., 2022). To achieve these goals of an organization's strategic plan, projects are often used (PMBOK, 2008). Approved projects must be assigned to teams preferably led by certified professionals, such Black Belt or Green Belts, whom have the necessary skills to conduct them applying the (Define – Measure – Analyse – Improve – Control) DMAIC approach and corresponding statistical techniques according characteristics of each project.

Lean Six Sigma (LSS) is a leading initiative for maximizing production efficiency and maintaining control over each step of the management process (George *et al*., 2005). Beyond the strategic benefits, LSS aims to clear up the manufacturing process of opportunities identification for problem-solving, waste reduction and reducing variability in processes (Gupta *et al*., 2020; Costa *et al*., 2021; Sunder *et al.*, 2018). Currently, the complementary relationship's LSS has been widely accepted in the corporate world and also has been recognized by more than 70 per cent of Fortune 500 companies (Antony, 2015).

Auto parts sector has grown around the world, with the United States, Germany, and China being the major global exporters, while Mexico, Brazil and Venezuela as major Latin America exporters. This sector has serious efficiency problems caused by high waste rates and unnecessary operations (Mancilla-Escobar *et al.* 2020).

LSS and DMAIC literature contains many descriptions of practical applications in industry, including the automotive industry sector. Mishra *et al.* (2021) describes a case study method with DMAIC applied to the Indian automotive industry and found improvements in productivity level and overall equipment effectiveness (OEE). Chaurasia *et al.* (2019) present a study with first through time and scrap reduction by LSS and DMAIC. Shokri (2019) investigated benefits of LSS to reduce the scrap rate in an automated production line of an automotive supplier using action research. Despite having some LSS and DMAIC application in automotive sector, they are methodologies still poorly applied in auto parts manufacturer according literature.

This article aims to present a detailed description of the entire process used in a structured improvement exercise. It is an empirical single longitudinal case study where Lean Six Sigma and DMAIC methodologies are applied as a way to reduce defects of aluminum automotive parts. Each DMAIC phase is described, including design of experiments and hypothesis testing. This way, The study can be used for those who intend to use the same type of improvement methodologies to conduct lean six sigma projects oriented to defect reduction in auto parts manufacturer.

This paper is organized as follows. In the next section, it was presented a previous literature review on LSS. Then, methodological procedures defined to achieve thestudy goal are described. Next, the empirical research results are presented according DMAIC sequence. At the end, the conclusion of the study and some future research suggestions are reported.

LITERATURE REVIEW

Lean manufacturing is a multifaceted concept (McLachlin, 1997) focused on systematic waste elimination through a set of practices that synchronize production with demand (Womack et al. 2007). The set of practices includes pull production, cross-functional work teams, Just in Time (JIT), continuous flow production, Total Quality Management (TQM), cellular manufacturing, Total Preventive Maintenance (TPM), Statistical Process Control (SPC), employee training, self-directed teams, problem-solving in small groups, work standardization and specific Human Resource Management practices (Bayou and Korvin, 2008; Doolen and Hacker, 2005; Karlsson and Åhlström, 1996; Panizzolo, 1998; Shad and Ward, 2003).

Six Sigma is a project-driven strategy (Kwak and Anbari, 2006) and its first adoption was in 1987 by Motorola's (Kahraman and Büyüközkan, 2008) resulting in more than 10 billion dollars saving (Yang and Hsieh, 2009). Since then, it has spread over many areas, including finance and health (Snee, 2004). Its benefits have been appreciated since 1990s and has also been widely acknowledged as a business strategy to improve profitability (Antony *et al*. 2007); a framework to eliminate defects, errors, or failures in process and business systems (Snee, 2004); and, also an analysis methodology (Kumar *et al*. 2008), as well as business culture (Schroeder *et al*. 2009).

More recently, a proposal called Lean Six Sigma (LSS) has been discussed. Its main purpose is to apply the concepts of the two approaches. The combination of the characteristics of both programs enabler greater performance (Pinheiro et al., 2013). According Salah *et al.* (2010), there are six application possibilities related to LSS in organizations:

(1) Lean Production as the main methodology and Six Sigma as complementary tool in Gemba Kaizen events;

(2) Six Sigma as a core methodology and Lean Production tools applied within the DMAIC framework;

(3) Lean Production and Six Sigma separately to address different problems according to project classification;

(4) Lean and Six Sigma in parallel to solve them problems, but separately;

(5) Applying Lean Production and Six Sigma continuously to attack the same problems;

(6) Applying Lean Production and Six Sigma simultaneously.

According Su *et al.* (2005), the six sigma uses a disciplined approach and its original characteristics are:

(1) Sequences and links of improvement tools within a global approach, known as DMAIC (Define, Measure, Analyse, Improve, Control);

(2) Integration of the human element and process for improvement, using an organization based on Champions, Black Belts and Green Belts;

(3) Attention to results and sustaining gains over time.

Table 1 shows the five DMAIC phases according Chua and De Feo (2005).

Table 1 – DMAIC phases according Chua and De Feo (2005).

Phase	Description
Define	After identifying potential projects and selecting the best one, through the construction of a decision team, the organization seeks to implement the selected project
Measure	This phase includes measurements of current process capabilities and identified the most important product or service parameters
Analyse	In this phase, the organization seeks to collect and analysis past and present information to identify the relationships and reasons for defects and variations in product and process characteristics
Improve	In this phase, based on previous data, some solutions, and remedies are proposed to overcome waste. In addition, the effectiveness and efficiency of these solution must be proven and implemented
Control	The decision team sets some standards and provides feedback to support improvements

RESEARCH METHODOLOGY

The study follows the DMAIC methodology (Chua and De Feo, 2005) to investigate the root causes of defects and offer the solutions to reduce them. Design of experiments, hypothesis testing and analysis of variance were applied. It was a single longitudinal case study with interviews in the DMAIC steps sequence.

The study was carried out in a manufacturing company that produces die-casting and machined aluminum auto parts for all the main vehicle manufacturers located in Brazil, located in São Paulo – Brazil with about 450 employees. The unit of analysis was selected for convenience of access to the researcher, considering the following requirements:

(1) Manufacturing industry;

(2) Certified quality management system;

(3) Independent areas for product development, process engineering and quality management;

(4) Experienced in continuous improvement tools (kaizen, lean tools, problem-solving methodologies);

(5) Management interested in LSS and DMAIC implementation;

(6) Multifunctional Team trained for Lean Six Sigma DMAIC e associated main Lean tools according ISO (2011).

Data were collected through semi-structured interviews, document analysis and direct field observations. The interviews were conducted in a semi-structured way. Statistical analysis was performed using Minitab (Bass and Lawton, 2009).

RESULTS

Auto Parts Industry Context

The auto parts manufacturing company in which this project was carried out is inserted in the context of the automotive industry supply chain. In this way, the company was exposed to strong competitive pressures related to product quality improvements and cost reduction. Given their negotiations strength in the supply chain, car manufacturers impose bold defect reduction targets on their suppliers. For auto parts suppliers, it is usually required that the next year's defect rate be equivalent to a portion (commonly half) of the previous year' rate. Simultaneously, some other product, process and systems requirements are increasingly demanding. In some cases, especially long-term value-added and high-volume supply contracts, the product price must be gradually reduced, year by year, assumption that the manufacturing process can and must be improved. Consequently, auto parts companies need to implement effective initiatives oriented to achieve these goals. The effort of these companies to seek to meet these car manufacturer requirements includes typically the hiring of professional qualified on a broad set of quality and continuous improvement tools. Some auto parts companies invest in training and certifying their professionals.

Project Selection Process

The project described in this article was selected among other alternatives by the following criteria:

(1) The auto part focused is produced in large volume all month;
(2) There were prospects of new business with the customer;
(3) The costs associated with defects were expressive, when compared with the other product;
(4) There was a high risk of additional costs arising from disruptions to the customer's production line.

Define

Firstly, a Project Leader was assigned to realize the project, which is oriented to defect reduction in die casting and machining process. The designated leader was already certified as Lean Six Sigma Green Belt and was an experienced engineer with mastery of improvement methods and good previous results in leading cross-functional teams (e.g., workshops kaizen, global 8D teams, PFMEA meetings). The project team was defined in a negotiation process between the project leader and the industrial director of the auto parts company. Other team members participated in the decisions and negotiations for team composition.

After studying immediately available data the project team decided to collect new data during about eight weeks on die-casting and machining process, the project team elaborated a Project Charter for the project (Table 2).

Table 2 - Project Charter.

Project Title	Reduction of rejection of die-casting and machining rearview housing support
Problem Statement	Reduction of rejections of die-casting and machining rearview housing support, which cause variability in the company's production volume and also additional costs and disturbances in the intermediate assembly process (customer) and possible production line stops at car manufacturers
Project Team	Project Leader (Certified Black Belt in training); Machining production Supervisor; Die-casting production Supervisor; Quality Analyst; Process Analysts (2); Maintenance Supervisor; Engineering Leader; Tool Shop Leader; Die-casting Operators (3); Machining Operators (3); Quality Inspectors (5)
Critical to Quality (CTQs)	Y1 = Rejection rate of Die-casting Parts / Y2 = Rejection rate of Machined Parts
Expected Benefits	Reduction of reject rate to less than 7% in die-casting process / and to less than 1% in machining process.
Estimated time	8 months

New data were collected about eight weeks to obtain an updated and initial understanding of the behaviour of the processes regarding the rejections of the selected auto part: Rearview Housing Support (RHS). Two control charts were elaborated: p-chart for rejection rate of die-casting parts (Figure 1), and p-chart for rejection rate of machining parts (Figure 2).

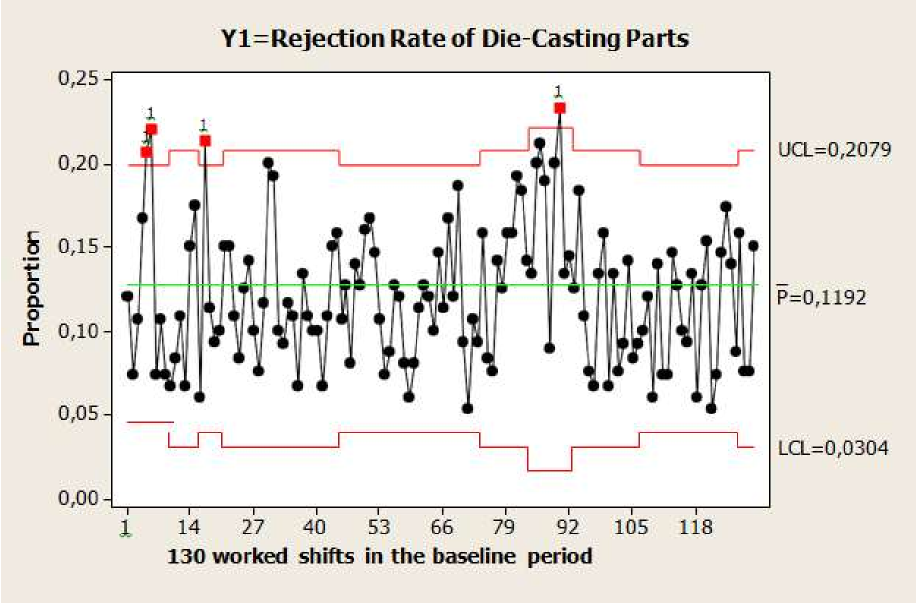

Figure 1 - p-chart for rejection rate of die-casting parts.

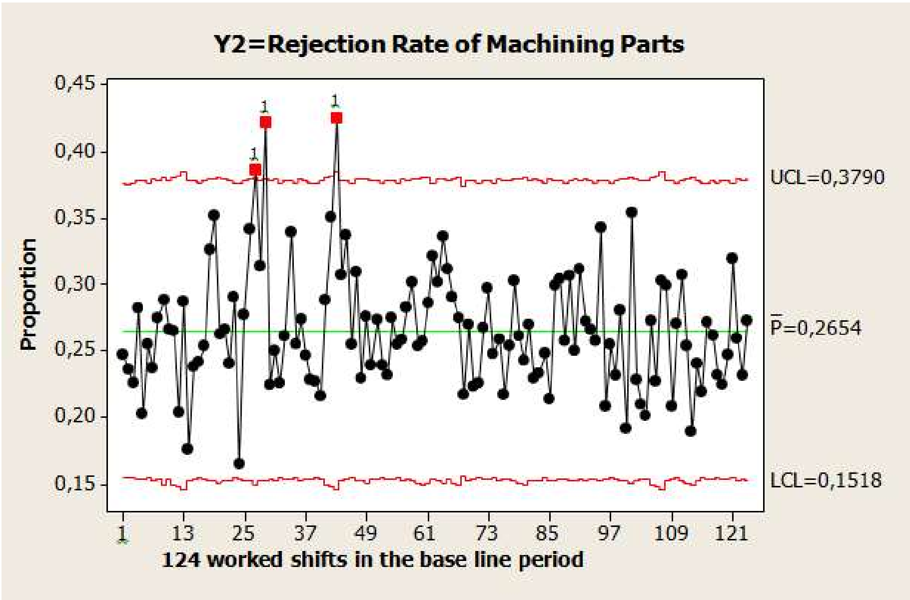

Figure 2 - p-chart for rejection rate of machining parts.

In both cases, each subgroup is composed to 90-150 parts (unequal sample sizes) in more than 100 production shifts in the baseline period. It was observed that both processes (die-casting and machining) presented special causes in a small portion of time (3 in 124 shifts for machining process and 4 in 130 shifts for die-casting process). It was observed that the rejection rate represented by average p, defective fraction, remains close to the central position throughout the entire 8 weeks period in both cases. Those findings obtained from these two p-charts enabled the project team to know the average defective fraction of each of the two processes (die-casting and machining). In this way, it was possible to establish goals based on the real situation of the respective processes (wrote down in "expected benefits" at Project Charter).

To obtain a first overview of the activities involved with the processes to be improved, the Project Team prepared a SIPOC (Suppliers, Input, Process, Output, Customers) matrix (Figure 3).

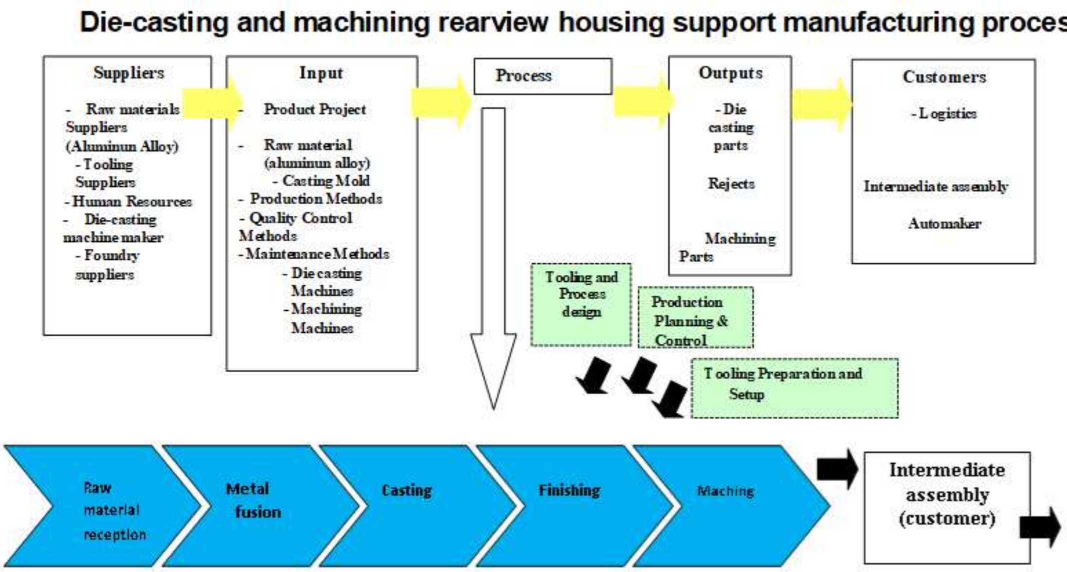

Figure 3 - SIPOC / Die-casting and machining housing support manufacturing process.

Measure

In the measure phase the Project Team was provoked to subdivide each SIPOC process step into sub-operations, and then, in each sub-operation, to search for variables with potential impact on the metrics of interest previously defined in the project charter (Y1 = Rejection rate of Die-casting Parts / Y2 = Rejection rate of Machined Parts).

The cross-functional team's technical and social effort resulted in a comprehensive matrix (Table 3) that summarize 30 possible variables with an impact on the two metrics of interest (defective fraction for die-casting and machining process), according to technical understanding and discussions.

Table 3 - Possible variables for defective fraction for die-casting and machining process.

Process Step	Sub-Operation	Possible Variables							
Raw material incoming	Chemical Analysis	Chemical Composition							
Alloy Preparation	Degassing	Degassing Time							
Injection	Lubricate Mold	Released agent application method							
	Dosage								
	Filling sleeve	Sleeve Filling	Metal Tempera-ture						
	Filling cavity (2nd phase)	Mold Temperature	Channels Volume	Attack Area	Injection Pressure	Foundry Components	Feeder Volume	Injection Speed	Tooling Dimension
	Compression (3rd phase)	Machine used for injection	Machine Mold Parallelism	Com-pression Time	Piston Diameter	Pump Pressure	Accumulat or Pressure	Multiplier Pressure	

	Solidification	Solidification Time							
	Extraction	Tooling polishing Method	Position of extractor pin	Injection Mold Taper	Released agent application method				
Machining	Part Fixation	Machining Fixation Method							
	Thread	Cutting tool type (Thread)	Machining Tool Holder Type	Cutting Speed	Advance-ment	Refrigeration			

The team's next move was to prioritize those variables around which the team would focus its efforts in the next phases. For this, the Project Team applied the tool called Cause and Effect Matrix. In doing so, among the 30 variables identified previously, 18 were submitted to a prioritization matrix (Table 4). As a result, seven key variables were prioritized (Table 5): x1 = mold temperature; x2 = metal temperature; x3 = release agent application method; x4 = injection speed (Phase 2); x5 = fixation method; x6 = tool holder type; x7 = cutting tool type (thread).

Table 4 - Cause and Effect Matrix: Variables identified in the processes

	Process Outputs / Process Inputs	Thread	Dimension	Cold Junction	Cacked	Pososity	TOTAL	% individual	% Cummulative
		10	8	8	8	6			
1	Mold Temperature	0	0	9	9	9	198	14%	14%
2	Metal Temperature	0	0	9	1	9	134	10%	24%
3	Release agent application method	0	0	4	9	4	128	9%	33%
4	Injection Speed (phase 2)	0	0	9	0	9	126	9%	43%
5	Machining Fixation Method	9	0	0	0	0	90	7%	49%
6	Machining Tool Holder Type	9	0	0	0	0	90	7%	56%
7	Cutting tool type (thread)	9	0	0	0	0	90	7%	62%
8	Position of extractor pins	0	0	0	9	0	72	5%	68%
9	Tooling Dimension	0	9	0	0	0	72	5%	73%
10	Attack Area	0	0	4	0	4	56	4%	77%
11	Feeding Method	0	0	4	0	4	56	4%	81%
12	Solidificastion Time	0	1	0	4	4	64	5%	86%
13	Injection Pressure (phase 1)	0	0	4	0	4	56	4%	90%
14	Refrigeration method (in thread operation)	4	0	0	0	0	40	3%	93%
15	Injection mold taper	0	0	0	4	0	32	2%	95%
16	Chemical Composition	0	0	0	4	0	32	2%	97%
17	Compression Time (phase 3)	0	0	0	0	4	24	2%	99%
18	Sleeve Filling (Phase 1)	0	0	1	0	1	14	1%	100%

Table 5 - Cause and Effect Matrix: Prioritized Variables.

	process outputs / process inputs	Threads	Dime nsion	Cold Junction	Cracks	Porosity	TOTAL	% individual	% Cummulative
		10	8	8	8	6			
1	Mold Temperature	0	0	9	9	9	198	14%	14%
2	Metal Temperature	0	0	9	1	9	134	10%	24%
3	Release agent application Method	0	0	4	9	4	128	9%	33%
4	Injection Speed (Phase 2)	0	0	9	0	9	126	9%	43%
5	Machining Fixation Method	9	0	0	0	0	90	7%	49%
6	Machining tool holder type	9	0	0	0	0	90	7%	56%
7	Cutting tool type - Thread	9	0	0	0	0	90	7%	62%

Die-casting Variables

Machining Variables

As a way to ensure the quality of the data to be collected, operational definitions were prepared for each of the five variables previously chosen by the project team (Table 6).

Table 6 - Operational Definitions.

x1 = Mold Temperature	To record the mold temperature measured with an optical pyrometer aimed at critical points of the fixed foundry matrix. Record measurement for every 50 pieces produced. For each temperature measured in the matrix, also record the temperature of thermal oil programmed according to the control panel. Write down every 50 pieces if there were production interruptions (loss of rhythm) longer than 10 minutes, and if there are how many interruptions for this group of 50 pieces produced.
x2 = Metal Temperature	To record the temperature indicated on the holding oven panel for every 50 pieces produced. Note if there is any indication of the use of unauthorized delay of the 2nd phase by the operator. Note if liquid metal leaks occurs.
x3 = 2n phase injection speed	To record the level of nitrogen load on the manometer at the beginning, middle and end of each shift. To note if there is any sign of piston seizing. To record the programmed speed for piston advance (2and stage speed)
x4 = Release agent application method	To note if there is any indication of non-compliance with the release agent application instructions. Note occurrences of “piece grab”.
x5 = Fixation Method Machining	To record if there are delays in the fixation operation due to difficulties in fixation. To note if there are any indication of non-compliance with part fixation instructions.
x6 = Machining Tool holder Type	To record the type of support (fixed or floating) used.
x7 = Cutting Tool – Type (Thread)	To record type of cutting tool thread type used. To record the number of accumulated parts produced with each cutting tool. To observe and make notes about cooling/lubrication conditions including solution concentration checks.
All Variables	Ask operator about operational difficulties and write it down.

As a way to ensure the quality of the data to be collected, operational definitions were prepared for each of the five variables previously chosen by the project team (Table 6).

In order to evaluate the measurement system regarding to the three rejections reasons (thread defect; cold junction defect, cracks), a Measurement System Analysis (M.S.A.) was carried out. An experiment using five inspectors and parts knowingly approved and disapproved for each of three reasons. The kappa values obtained are shown in Table 7. It is observable that all Kappa are above 0,7 which indicates an acceptable measurement system (Bass and Lawton, 2009).

Table 7 - Measurement System Analysis – Summary of results.

Thread

Kappa	B	A
C	0,852652	0,83731
A	0,879725	
Analyse result	There is good agreement between the 3 operators	

Kappa A	Kappa B	Kappa C
0,839744	0,854932	0,876084

Cold junction

Kappa	B	A
C	0,78022	0,794521
A	0,877607	
Analyse result	There is good agreement between the 3 operators	

Kappa A	Kappa B	Kappa C
0,905149	0,837134	0,863388

Cracks

Kappa	B	A
C	0,839194	0,889636
A	0,921169	
Analyse result	There is good agreement between the 3 operators	

Kappa A	Kappa B	Kappa C
0,953789	0,906015	0,937343

As this project use discrete data, we calculate the sigma level using defect proportion and Final Process Yield before improvements according Figure 4 and 5 and Tables 8 and 9).

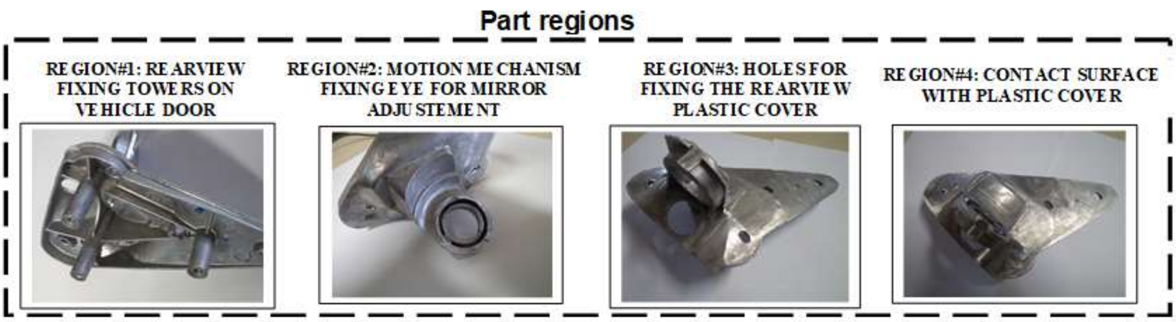

Figure 4 - Part regions.

Table 8 - Defect Opportunities in each part region.

Customer requirement by region	defect opportunities numbering for each part region			
	Region#1	Region#2	Region#3	Region#4
Fixation thread	Fillet of three towers (OD#1)	n/a	n/a	n/a
Dimensions	Height (OD#2)	Diameters (OD#6) Chamfers (OD#7)	Diameters (OD#11)	Curvature (OD#12)
Cold junction	free from defects (OD#3)	free from defects (OD#8)	n/a	n/a
Cracks	free from defects (OD#4)	free from defects (OD#9)	n/a	n/a
Porosity	free from defects in the first three threads (OD#5)	max 3 pores with max 1.00 mm and minimum distance of 15 mm from each other (OD#10)	n/a	n/a

Table 9 - Data for Final Process Yield calculation – before improvements

Reason(s) for part rejection	Amount of rejected parts	Percentage
Only OD#1 (Thread)	3952	60.6%
Only OD#3 or OD#8 (Cold Junction)	2111	32.4%
Only OD#4 or OD#9 (Crack)	303	4.6%
Only OD#2 or OD#6 or OD#7 or oD#11 or OD#12 (Dimension)	49	0.8%
Only OD#5 or OD#10 (Porosity)	39	0.6%
Parts rejected with 2 or more defects	71	1.1%
Total rejected parts	6525	100%

DO = Defect Opportunities in each part = **12**
NU = number of units processed = **17.220** parts
TND = Total number of defects occured = **6.612** defects in 6.525 defective parts

17.220 units
12 def.opport.
6.612 defects

YIELD = $\left(1 - \dfrac{6.612}{12 \times 17.220}\right) \times 100$ = **96,80** => **3,4 sigmas**

Figure 5 - Final Process Yield calculation – before improvements.

The main reasons for rejecting parts are shown in Figure 6.

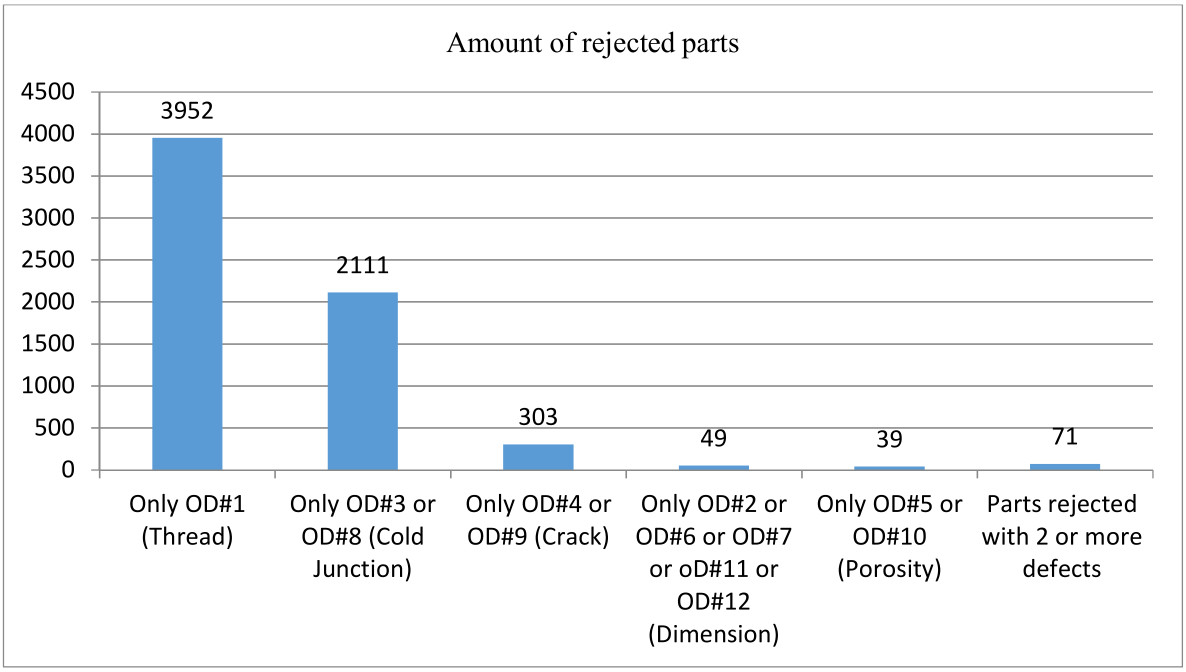

Figure 6 - Pareto Chart – Main reasons for rejecting parts.

Thread, cold junction and cracks are the three main reasons for part rejection. In the next phase (analyse), the team explore how to avoid these 3 reasons for part rejection, oriented by the seven key variables previously selected.

Analyse

Searching for root causes and corresponding solutions, the project team developed a specific cause and effect studies using Ishikawa Diagrams for each one of all seven key variables previously selected: x1 = mold temperature; x2 = metal temperature; x3 = injection speed (Phase 2); x4 = release agent application method; x5 = fixation method; x6 = tool holder type; x7 = cutting tool type (Thread).

We presented below two examples of these application. Figure 7 present root cause analysis using Ishikawa's Diagram for variable x1 = mold temperature (one of the selected variables prioritized in die-casting process), while Figure 8 shows the same for x7 = cutting tool Type (Thread), one of the selected variables prioritized in machining process.

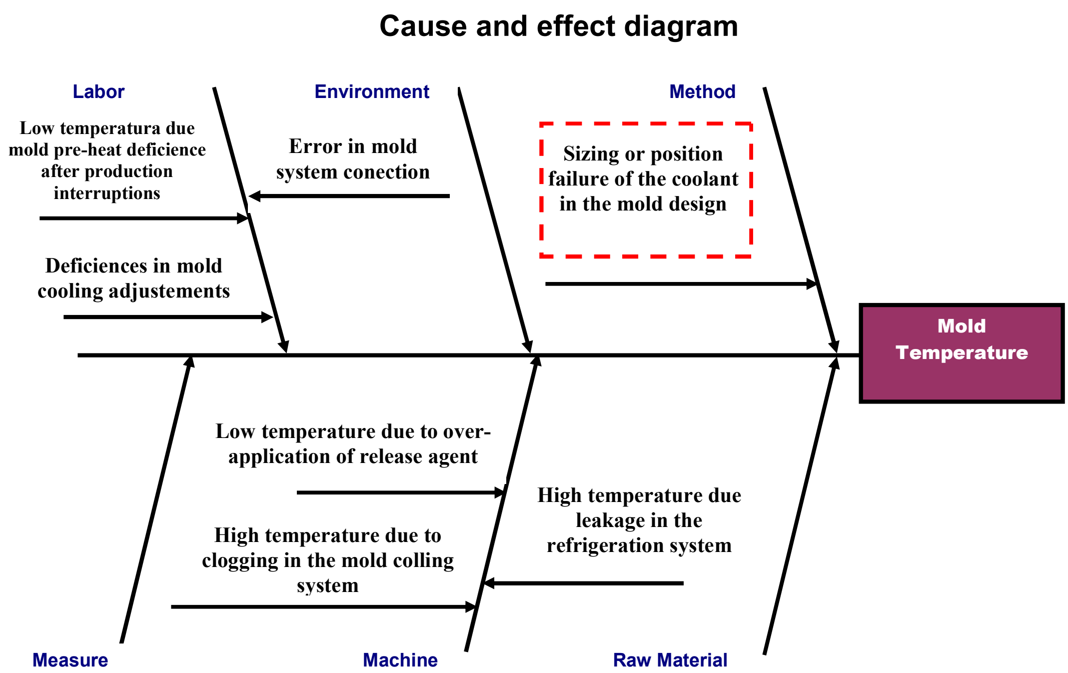

Figure 7 - Root cause analysis for selected variable x1 (mold temperature).

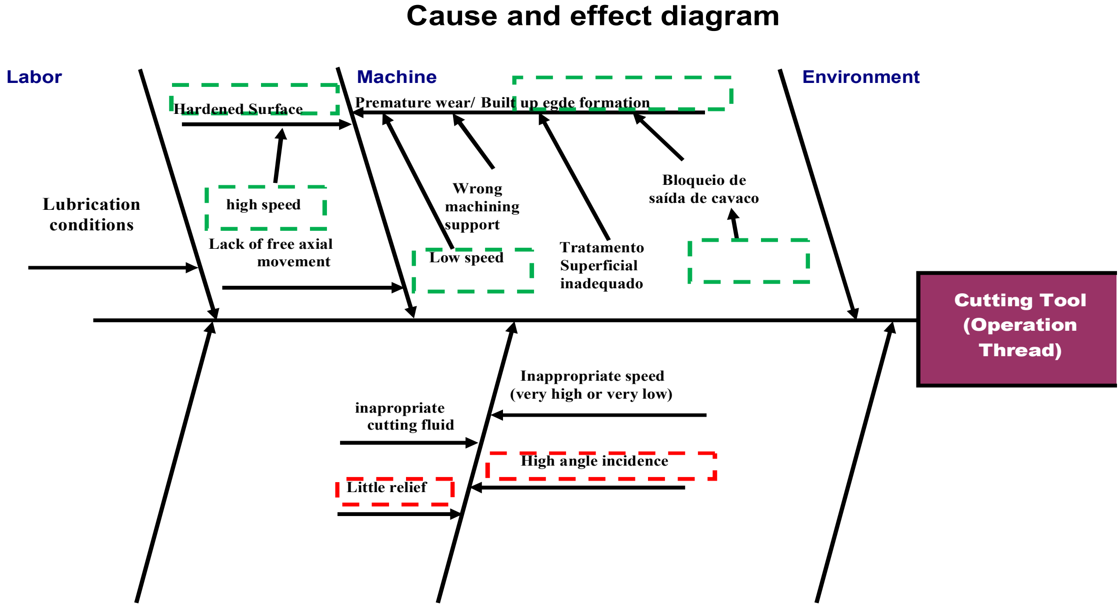

Figure 8 – Root cause analysis for selected variable x7 (cutting Tool Type - Thread).

A series of factorials experiments was carried out to validate the cause and effect relationships between each of the seven selected variables and effects on the defective fraction. This was done separately for the die-casting and machining process.

Die-casting Variables

Firstly, we run a 2^k factorial experiment for the four die-casting selected variables: x1 = mold temperature; x2 = metal temperature; x3 = 2nd phase injection speed (Figure 9) and, x4 = release agent application method.

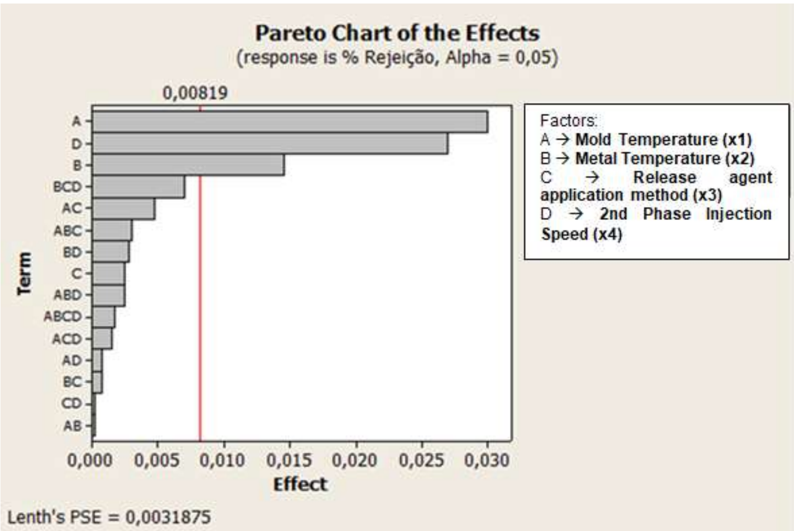

Figure 9 - Pareto Chart of the Effects of the first experimental running – Die-casting.

With the result above, it was decided for doing the second experimental running including only the three variables that indicates an effect in the first experimental running: x1 = mold temperature; x2 = metal temperature; x3 = 2nd phase injection speed. The results of the second experimental running are shown in Figure 10 (Pareto) and Figure 11 (interactions).

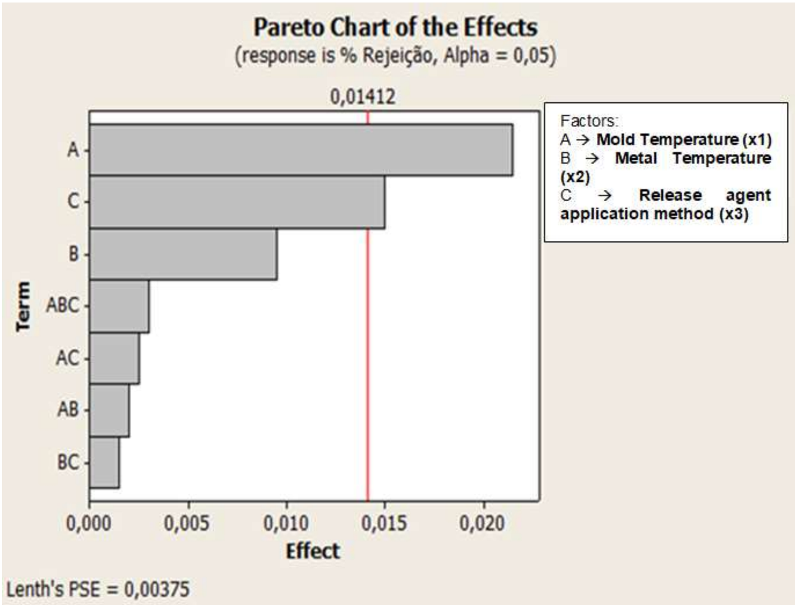

Figure 10 - Pareto Chart of the Effects of the second experimental running – Die casting.

In Figure 10, we observe, with 95% confidence, statistical effect only for 2 die-casting variables: x1 = mold temperature; and, x4 = 2^{nd} phase injection speed.

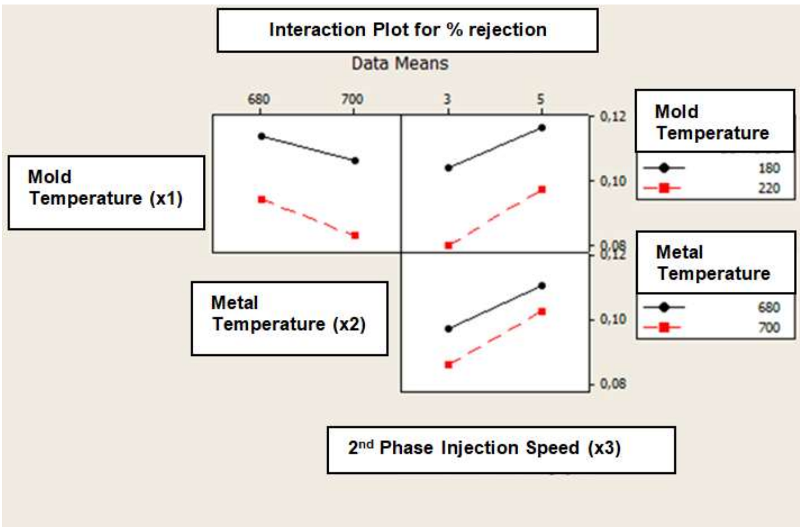

Figure 11 - Interaction on second experimental running – Die Casting.

In Figure 11, it was observed no interaction between variables in the working bands used.

But, during the second experiment we note that the minimum defective fraction correspond to combination between Mold Temperature in the level = 220º C, Metal Temperature in the level = 700º C, and injection speed (Phase 2) in the level 3 meters per second (Figure 12).

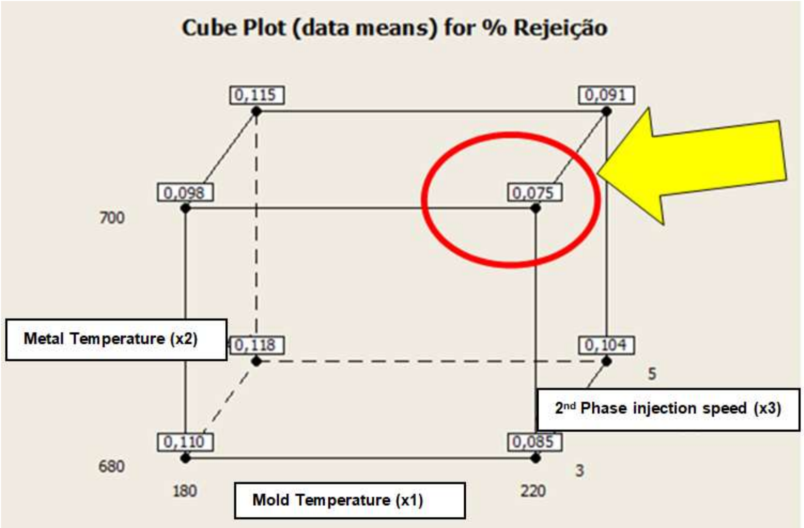

Figure 12 - Best combination of variables found during second experimental running – Die casting.

From this finding, the levels of these three variables were standardized as process target: 220ºC for mold temperature; 680ºC for metal temperature; and 3 m/s for 2nd phase injection speed. The implementation of this variable combination contributed to obtain expressive reduction in fraction defective in machining process, as will be illustrated later.

Machining Variables

For machining variables, we follow the same experimental strategy. Firstly, we run a 2^k factorial experiment for the three machining selected variables: x5 = fixation method; x6 = tool holder type; and, x7 = cutting tool type - thread (Figure 13).

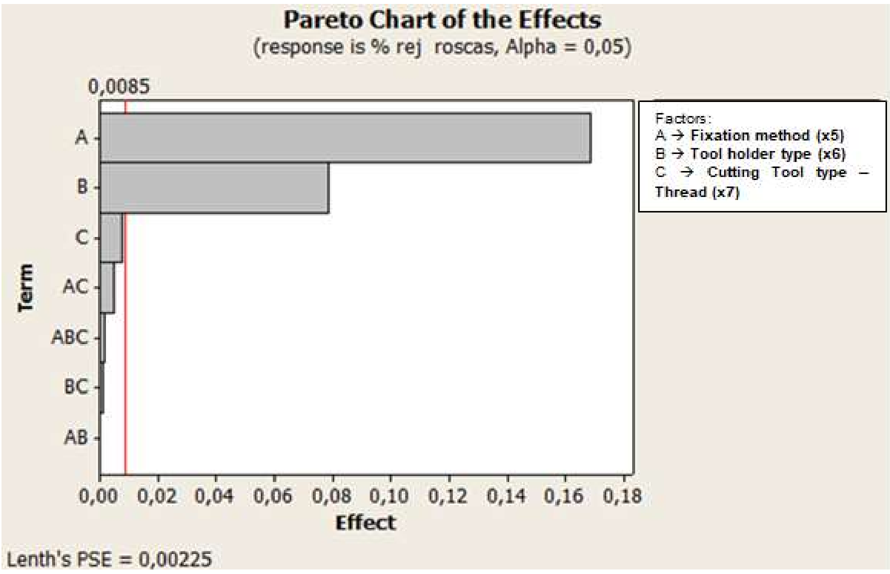

Figure 13 - Pareto Chart of the Effects of the first experimental running – machining.

With the result above, it was decided for doing the second experimental running including only the two variables that indicates an effect in the first experimental running: x5 = fixation method; x6 = tool holder type. The results of the second experimental running are shown in Figure 14 (Pareto) and 15 (interactions).

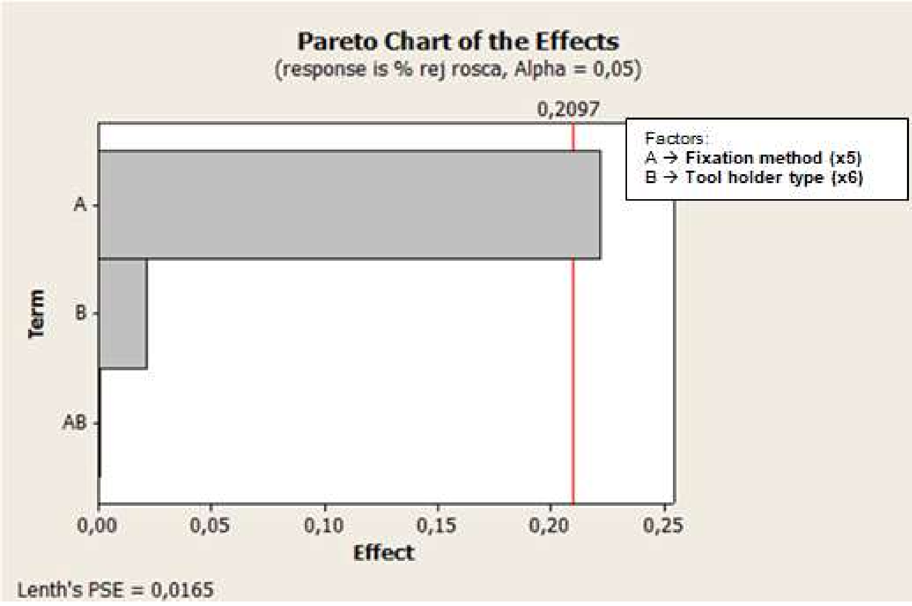

Figure 14 - Pareto Chart of the Effects of the second experimental running – machining.

In Figure 14, we observe, with 95% confidence, statistical effect only for one machining variables: x5 = fixation method.

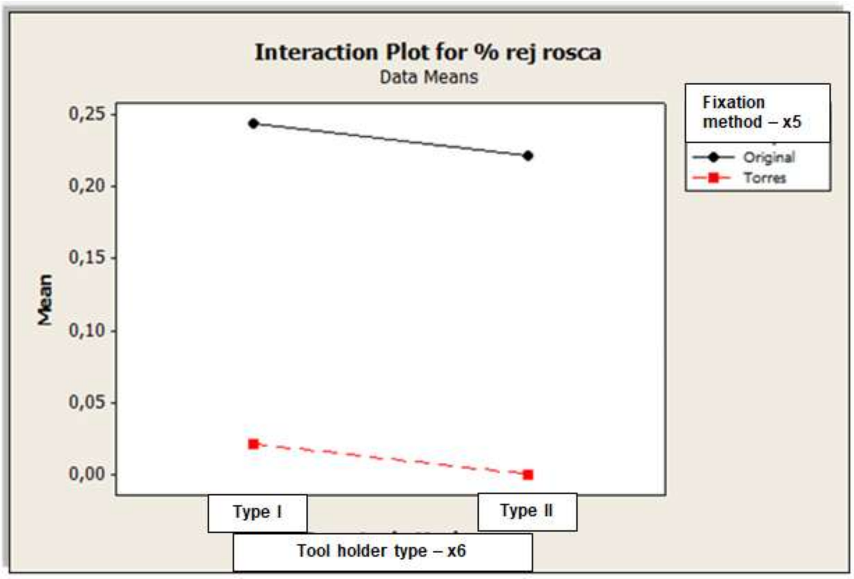

Figure 15 - Interaction on second experimental running – machining.

Note: "Torres" is the name of the alternative fixation method.

In the Figure 15, it is observed no interaction between variables in the working bands used. But, during the second experiment we note that the minimum defective fraction correspond to combination between type II (alternative) fixation method - x5, named “Torres”, and the type II (alternative) tool holder – x6 (Figure 16), named “Floating”.

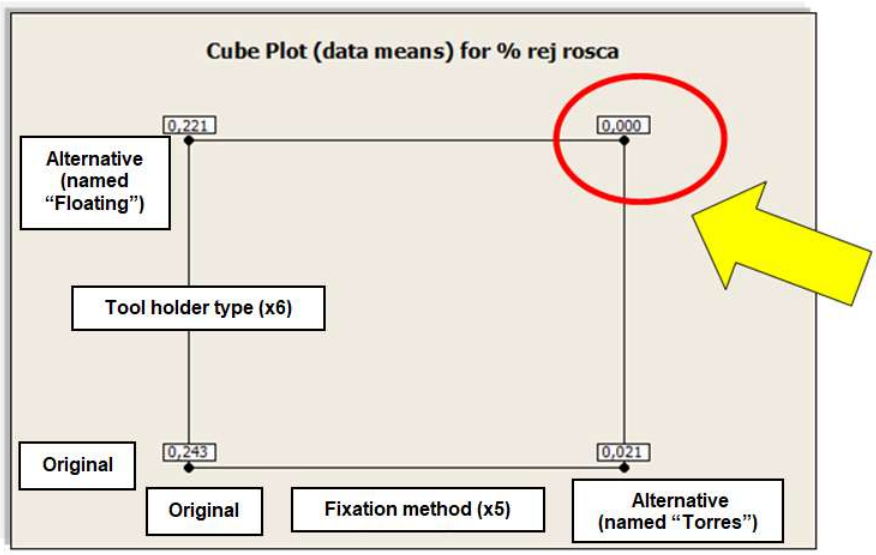

Figure 16 - Best combination of variables found during second experimental running – die casting.

In similar way to what was done for the die-casting process, from this finding, the levels of these two variables were standardized as process target: type II (alternative) fixation method and type II (alternative) tool holder. The implementation of this variable combination contributed to obtain expressive reduction in fraction defective in machining process, as will be illustrated later.

Improve

With the data and knowledge obtained in the previous DMAIC phases, the project team met to identify possible and best solutions to act on identified root causes and achieve the project goals sustainably (Figure 17).

Figure 17 - Project Team meetings.

Firstly, the team leader decided to level all members with all information available, since not all members had participated in all analyses. After leveling, a brainstorming session was held in the company room reserved for improvement meetings and visual management (Figure 17). The possible solutions presented were discussed and ranked using corporative criteria. As a result, four solutions were defined for implementation (Table 10).

Table 10 - Decision Matrix.

Possible Solutions	Easy of deployment	Cost for implement	Benefit	Time to implement	Final Score
Thermal oil using	5 Very Easy	3 Average	4 Relevant	5 Very Fast	300 Approved Solution
New Machining Fixation Method	4 Easy	4 Cheap	5 Very High	4 Fast	320 Approved Solution
New casting mold	3 Medium	1 Expensive	3 Some	1 Late	9 Not approved
Improve maintenance of foundry components	5 Very easy	4 Cheap	3 Some	4 Fast	240 Approved Solution
Alternative tool holder type	5 Very Easy	4 Cheap	4 Relevant	4 Fast	320 Approved Solution
Machining Tool with more relief and small angle	5 Very Easy	3 Average	2 Low	5 Very Fast	150 Not approved

After implementing all the four solutions, data related to defective fraction in die-casting and machining processes were collected, and two corresponding hypothesis test were applied (Figure 18 and 19).

```
Test and CI for Two Proportions

Sample      X      N   Sample p
1        2052  17220   0,119164
2         480   6210   0,077295

Difference = p (1) - p (2)
Estimate for difference:  0,0418691
99% CI for difference:  (0,0310689; 0,0526692)
Test for difference = 0 (vs not = 0):  Z = 9,11  P-Value = 0,000

Fisher's exact test: P-Value = 0,000
```

Figure 18 - Hypothesis Test for die-casting improvements.

```
Test and CI for Two Proportions

Sample      X       N    Sample p
1        4402   16965    0,259475
2          18    6141    0,002931

Difference = p (1) - p (2)
Estimate for difference:  0,256544
99% CI for difference:  (0,247695; 0,265393)
Test for difference = 0 (vs not = 0):  Z = 43,80  P-Value = 0,000

Fisher's exact test: P-Value = 0,000
```

Figure 19 - Hypothesis Test for machining improvements.

For both cases, since p-value < alpha, it can be said, based on the samples collected, with 99% confidence, that the population proportions are different, thus proving that both processes have improved.

Using the same procedure applied in the measure phase of DMAIC, we calculate the improved sigma level using defect proportion and Final Process Yield according Table 11 and Figure 20).

Table 11 - Data for Final Process Yield calculation – improved processes.

Reason(s) for part rejection	Amount of rejected parts	Percentage
Only OD#3 or OD#8 (Cold Junction)	409	83.3%
Only OD#4 or OD#9 (Crack)	49	10.0%
Only OD#2 or OD#6 or OD#7 or oD#11 or OD#12 (Dimension)	13	2.7%
Only OD#5 or OD#10 (Porosity)	8	1.6%
Only OD#1 (Thread)	8	1.6%
Parts rejected with 2 or more defects	4	0.8%
Total rejected parts	491	100%

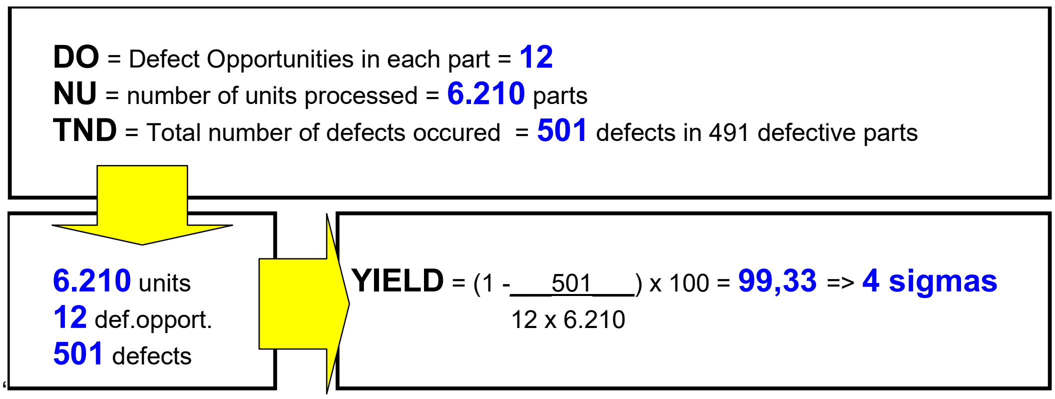

Figure 20 - Final Process Yield calculation - improved processes.

We concluded that the sigma level rose from 3.4σ (Figure 5, in the Measure Phase) to 4σ (Figure 20).

Control

As a way to sustain the improvements made the project team create and reviewed a long list of documents related to die-casting (Table 12) and machining processes (Table 13).

Table 12 - Created or reviewed documents for die-casting process.

Control Item	Responsibility	Document
Tooling condition – Injection Mold	Maintenance	Mold Maintenance Checklist
Injection Machine condition	Maintenance	Preventive Maintenance Report
Mold release centre condition	Maintenance	
Casting components condition (piston; bushing; rod) **(Reviewed)**	Maintenance	
Optical Pyrometer condition **(Reviewed)**	Maintenance	
Thermal Oil Machine condition **(Reviewed)**	Maintenance	
Nitrogen Cylinder conditions **(Reviewed)**	Maintenance	
Injection Process Parameters including thermal oil temperature and 2nd stage speed **(Reviewed)**	Process	Set up and Process Monitoring Report
Standard parts for R&R Testing for Cold Junction **(New)**	Quality	Standard Part Identification Label
Standard parts for R&R Testing for Cracks **(New)**	Quality	

Table 13 - Created or reviewed documents for machining process.

Control Item	Responsibility	Document
Product Features	Quality	Control Plan
CNC Lathe condition	Maintenance	Preventive Maintenance Report
Floating Support Condition	Maintenance	
Machining Fixture Condition **(Reviewed)**	Maintenance	
Machining Process Parameters **(Reviewed)**	Process	Process Control Report
Machining Tools Specification **(Reviewed)**	Process	
Machining Manufacturing Method **(Reviewed)**	Process	Standard Operating Procedure (SOP) – Machining Operation
Machining Setup Method **(Reviewed)**	Process	
Effective Operation of Machining Fixture	Process	
Effective Operation of Floating Support **(New)**	Process	
Parts Traceability from different production shifts **(New)**	Quality	
Qualification for defective parts segregation **(New)**	Quality	Standard Operating Procedure (SOP) – Inspectors Qualification

Standard parts for R&R Testing for Thread **(New)**	Quality	Standard Part Identification Label

As the company works in an environment regulated by quality systems internal and external audit, these documents could contribute to maintain the improvement over time and also could be used to internal training. Finally, the company decided to implement a quarterly process capability analysis to measure the process performance over time for both processes: die-casting and machining, as exemplified in Figure 21 and 22, respectively.

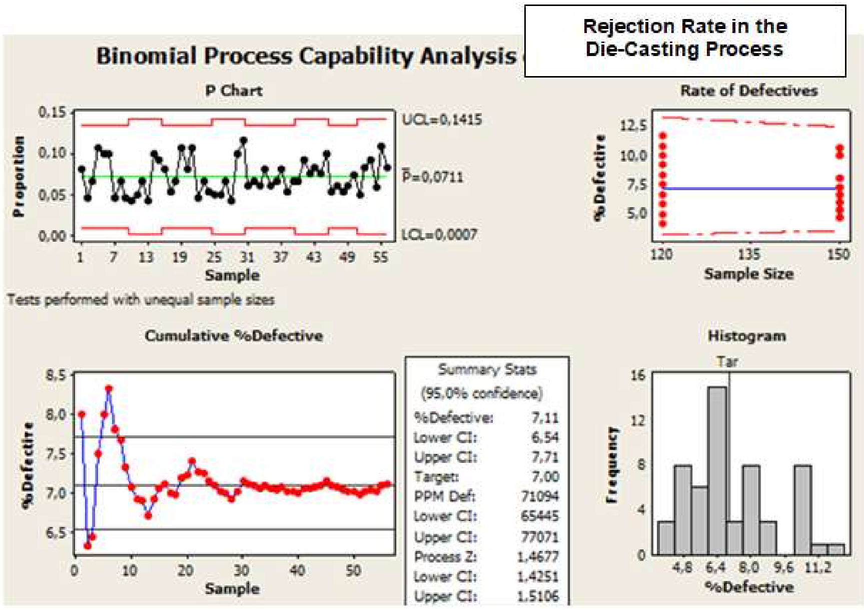

Figure 21 - Periodic process Capability Analysis – Die casting process.

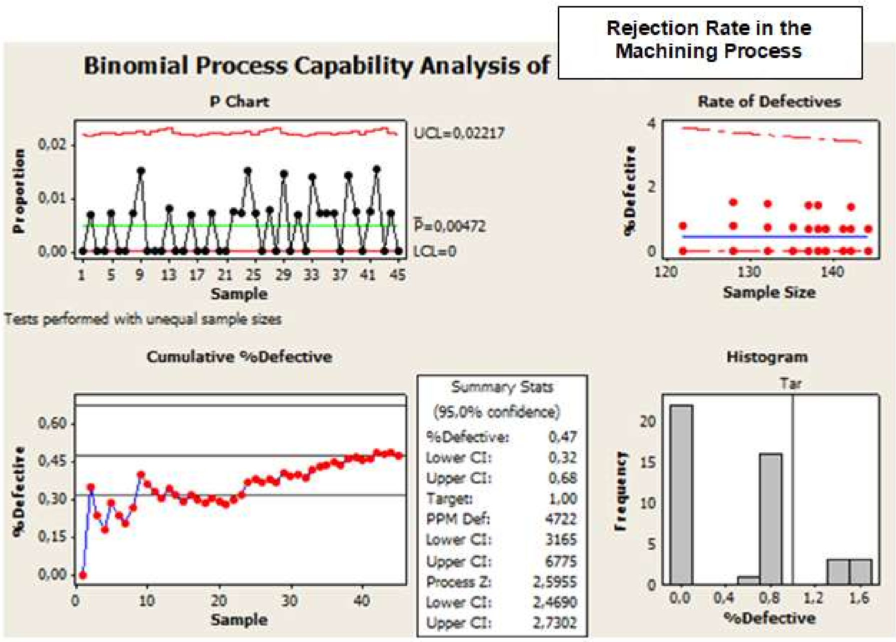

Figure 22 - Periodic process Capability Analysis – machining.

The results shown in Figure 21 and 22 revealed that in the first two quarters the process capability indicated that the improvements made were sustainable for both the process (die-casting and machining), thus validating both the solution set and the control measures.

CONCLUSIONS

Lean Six Sigma has been considered one of the most effective approaches for business transformation. The project described in this study used DMAIC methodology to investigate the root causes of defects and offer the solutions to reduce them to achieve project goal oriented to defect reduction in auto parts die casting and machining processes. Using DMAIC methodology (according Chua and De Feo, 2005) and associated tools and statistical techniques, the project team achieved the project goal.

According to the process capability analysis shown at the end of control phase (Figures 20, 21 and 22), the expected benefit of reduction of reject rate to less than 7% in die-casting process and to less than 1% in machining process, established in Define phase (Table 2) were both achieved. Moreover, the sigma level of both combined process rose from 3.4σ (Figure 5) to 4σ (Figure 20), sustainably. From this successful experience, the company replicated the project for similar products. This study can be used as a reference for researches, managers and engineers to conduct lean six sigma projects oriented to defect reduction in auto parts industries. Despite having some LSS and DMAIC application in automotive sector, they are methodologies still poorly applied in auto parts industry according literature.

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REFERENCES

Antony, J. (2015), “Challenges in the deployment of LSS in the higher education sector: Viewpoints from leading academics and practitioners”, International Journal of Productivity and Performance Management.

Antony, J., Antony, F. J., Kumar, M. and Cho, B. R. (2007). “Six sigma in service organisations: Benefits, challenges and difficulties, common myths, empirical observations and success factors”, International journal of quality & reliability management, Vol. 24 No. 3, pp. 294-311.

Bass, I., and Lawton, B. (2009). Lean six sigma using SigmaXL and Minitab. McGraw Hill Professional.

Bayou, M. E. and De Korvin, A. (2008). “Measuring the leanness of manufacturing systems—a case study of Ford Motor Company and General Motors”, Journal of Engineering and Technology Management, Vol. 25 No 4, pp. 287-304.

Chaurasia, B., Garg, D., & Agarwal, A. (2019), “Lean Six Sigma approach: a strategy to enhance performance of first through time and scrap reduction in an automotive industry”, International Journal of Business Excellence, Vol. 17, No. 1, pp. 42-57.

Costa, L. B. M., Godinho Filho, M., Fredendall, L. D. and Ganga, G. M. D. (2021), “Lean six sigma in the food industry: Construct development and measurement validation”, International Journal of Production Economics, Vol. 231, pp. 107843.

Chua, R. C. H. and DeFeo, J. A. (2006), Juran's quality planning and analysis: For enterprise quality. Tata McGraw-Hill Education.

Daniyan, I., Adeodu, A., Mpofu, K., Maladzhi, R. and Katumba, M. G. K. K. (2022), “Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly process in the railcar industry”, Heliyon, e09043.

Doolen, T. L. and Hacker, M. E. (2005), “A review of lean assessment in organizations: an exploratory study of lean practices by electronics manufacturers”, Journal of Manufacturing systems, Vol. 24 No. 1, pp. 55-67.

George, M. L., Maxey, J., Rowlands, D. T., & Upton, M. (2004). Lean six sigma pocket toolbook. McGraw-Hill Professional Publishing.

Gupta, S., Modgil, S. and Gunasekaran, A. (2020), “Big data in lean six sigma: a review and further research directions”, International Journal of Production Research, Vol. 58 No. 3, pp. 947-969.

International Organization for Standardization. ISO 13.053-1: Quantitative methods in process improvement – Six Sigma Part 1: DMAIC methodology. Genebra: ISO, 2011.

Kahraman, C., and Büyüközkan, G. (2008), “A Combined Fuzzy AHP and Fuzzy Goal Programming Approach for Effective Six-Sigma Project Selection”, Journal of Multiple-Valued Logic & Soft Computing, Vol. 14 No. 6.

Karlsson, C. and Åhlström, P. (1996). “Assessing changes towards lean production”, International Journal of Operations & Production Management.

Kwak, Y. H., and F. T. Anbari. (2006), "Benefits, Obstacles, and Future of Six Sigma Approach", Technovation, Vol. 26 No. 5–6, pp. 708–715.

Mancilla-Escobar, J., Maccasi-Jaurequi, I., Raymundo-Ibañez, C. and Perez, M. (2020, March). Layout Lean model of production management based on change management to improve efficiency in the production of packaging in auto parts sector SMEs. In IOP Conference Series: Materials Science and Engineering (Vol. 796, No. 1, p. 012014). IOP Publishing.

McLachlin, R. (1997), "Management initiatives and just-in-time manufacturing", Journal of Operations management, Vol. 15 No. 4, pp. 271-292.

Mishra, Y., Sharma, M. K., Yadav, V., Meena, M. L. and Dangayach, G. S. (2021), "Lean Six Sigma implementation in an Indian manufacturing organisation: a case study", International Journal of Six Sigma and Competitive Advantage, Vol. 13 No. 1-3, pp. 76-100.

Panizzolo, R. (1998), "Applying the lessons learned from 27 lean manufacturers.: The relevance of relationships management", International journal of production economics, Vol. 55 No. 3, pp. 223-240.

Pinheiro, T. H., Scheller, A. C., & Miguel, P. A. C. (2013), "Integração do seis sigma com o lean production: uma análise por meio de múltiplos casos", Revista Produção Online, Vol. 13 No. 4, pp. 1297-1324.

PMBOK, G. (2008). Um guia do conjunto de conhecimentos em gerenciamento de projetos (guia pmbok®). Project Management Institute, Inc. EUA.

Salah, S., Rahim, A. and Carretero, J. A. (2010), "The integration of Six Sigma and lean management", International Journal of Lean Six Sigma.

Schroeder, R. G., Linderman, K., Liedtke C. and Choo, A.S. (2009), "Six Sigma: Definition and Underlying Theory." Quality Control and Applied Statistics, Vol. 54 No. 5: pp. 441–445.

Shah, R. and Ward, P. T. (2003), "Lean manufacturing: context, practice bundles, and performance", Journal of operations management, Vol. 21 No. 2, pp. 129-149.

Shokri, A. (2019), "Reducing the scrap rate in manufacturing SMEs through lean six sigma methodology: An action research", IEEE Engineering Management Review, Vol. 47 No. 3, pp. 104-117.

Snee, R. D. (2004), "Six-Sigma: The Evolution of 100 Years of Business", International Journal of Six Sigma and Competitive Advantage, Vol. 1 No. 1: pp. 4-20.

Su, C. T., Chiang, T. L. and Chiao, K. (2005), "Optimizing the IC delamination quality via six-sigma approach", IEEE Transactions on Electronics Packaging Manufacturing, Vol. 28 No. 3, pp. 241-248.

Sunder, V.M., Ganesh, L. S. And Marathe, R. R. (2018), "A morphological analysis of research literature on Lean Six Sigma for services", International Journal of Operations & Production Management.

Womack, J. P., Jones, D. T. and Roos, D. (2007), " The machine that changed the world: The story of lean production--Toyota's secret weapon in the global car wars that is now revolutionizing world industry. Simon and Schuster.

Yang, T. and C. H. Hsieh (2009), "Six-Sigma Project Selection Using National Quality Award Criteria and Delphi Fuzzy Multiple Criteria Decision-Making Method", Expert Systems with Applications, Vol. 36 No. 4: pp. 7594–7603.

Synergies between Quality management and Knowledge management: 4.0 shop floor competency management model

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STRUCTURED ABSTRACT

Purpose - This research aims to deepen the integration of Knowledge Management (KM) in Quality Management (QM), identify their main synergies, and demonstrate how this complementarity can lead to systematic and continuous knowledge management.

Design/methodology/approach - This work was supported by an intrinsic single case study presenting an ongoing competency management project in a company Margres – Ceramic Tiles, located in Portugal.

Findings– This paper presents a theoretical contribution identifying the QM and KM key elements and describing how they can be interlinked. Consequently, a competency management model was proposed, structured in four main stages: 1 – Identification of competencies; 2 – Definition of competencies and Standard works; 3 - Competencies matrix; and 4 - Positioning matrix.

Research limitations/implications- The results are restricted to a singular case study focused only on the shop floor level.

Practical implications – The competency management model can help other organizations solve shop floor problem competencies. This project exemplifies how Human Resource Management and Quality Management professionals can work together to systematize knowledge management, which is so essential in the industry 4.0 context.

Originality/value - In addition to deepening the interrelationship of QM and KM, it presents an original model to implement the synergies between both.

Keywords: Knowledge management, Quality management, shop floor competencies, Industry 4.0.

Paper type : Case study

INTRODUTION

People are active elements and agents of change, leading organizations to achieve competitive advantage (Andalib, Tavakolan and Gatmiri, 2018). Thus, knowledge and skills management is increasingly essential in a competitive context (Berio and Harzallah, 2005). The manufacturing companies develop more complex products integrating technological components supported by Industry 4.0 (Baotong Chen *et al.*, 2017). However, at the same time, shop floor operators are getting older due to demographic issues and there is a lack of attractiveness for younger people for these activities. Therefore, these companies need to develop their employees' competencies and make this operational level more attractive to the next generations (Hertle *et al.*, 2015).

Thus, competency management models seem to be a promising approach, allowing employees to evolve and adapt to industry challenges and enhancing communication, collaborative work, and learning skills (Krijnen, 2007; Holm *et al.*, 2014; Holm, 2018). However, implementing competency management is not always easy, as it requires resources, time, money, and the availability of shop floor operators (Mavrikios *et al.*, 2013). QM can help organizations to face this challenge through the context management approaches, process management principles, and continuous improvement philosophy since KM is one of its key elements. (Akdere, 2009).

This research assumes that the interaction of QM and Human Resources enhances the symbiosis between both, helping develop problem-solving shop floor competencies in the 4.0 industry era. Based on the literature review and a case study, this research intends to deepen the integration of KM in QM models, identify the main synergies between them, and demonstrate how these synergies can lead to systematic and continuous knowledge management. Thus, the main research questions are: What are the main synergies between QM and KM? How can this symbiosis support a competency management model?

To reach these goals, the literature review discusses competencies and KM, presents an overview of competency management challenges for shop-floor operators in industry 4.0, and finally explores the synergy between QM and KM.

Then, this paper presents a case study based on a continuous improvement project integrated into the company's QM System.

Subsequently, the results and discussion are presented to identify the QM and KM synergies and how these can be integrated into the competency management model. Finally, the main conclusions are drawn, pointing out some guidelines for developing organizational KM.

LITERATURE REVIEW

Competency and Knowledge Management (KM)

Currently, KM is an increasingly important area since Human is becoming the most important organization's asset. Moreover, employee competencies are the most significant factor for generating profits, as they impact all processes (Isik, 2009). KM allows value creation for the organization by focusing on the employees' skills development, mainly critical thinking, communication, and technological skills (Jashapara, 2004).

Furthermore, organizations need to determine the necessary knowledge, know where it is and establish mechanisms that allow its transmission among the collaborators. According to Jashapara, (2004, p.14) KM can be defined as "the learning processes associated with the exploration and sharing of human knowledge (tacit and explicit) to increase the intellectual capital and organizational performance." As a result, skills and competencies are the main components of the learning process and KM.

Competency can be understood at two levels: a concrete performance or a personality trait. characteristic. For example, by making the analogy with an iceberg, the individual skills, knowledge, and competencies in its visible area produce results in the work context. The other invisible part comprises the personal motives, traits, values , and self-concept, which condition behavior (Lyons, 2003). Based on this perspective, other authors defined the following competency classes: technical and methodological; social, communicative and personal; and activity competencies (Hertle *et al.*, 2015).

Thus, managing competencies implies theoretical, practical, and methodological knowledge. When invested in the action, the theoretical knowledge unfolds into technical knowledge (defines what to do) and methodological knowledge (how to do it). Only the appropriation of knowledge to implement actions allows the development of competencies, employee development, and, consequently, organizational benefits (Bitencourt, 2004).

From a job market perspective, competency is defined as the knowledge and skills that any individual must have to successfully face a professional challenge and manage a career in turbulent, flexible, and evolving contexts (Huff-Eibl *et al.*, 2011).

Currently, competency management is strategic once it allows better results through the effective participation of people in the production, acquisition, and dissemination of knowledge (Bitencourt, 2004). Moreover, it can be an essential contribution at both levels, organizational and individual, identifying the knowledge that employees or the organization must possess to achieve their goals (Brandão and Bahry, 2005).

Competency management can be seen as a systematized process to set professional profiles, guiding efforts toward the planning, developing, and evaluating competencies at different levels. Its objective is to minimize the potential gap between what employees can do (current competencies) and what the organization expects (needed competencies) (Brandão and Bahry, 2005). So, this kind of competency program comprises several tasks, namely: (1) mapping and description of competencies; (2) measurement of competencies; (3) remuneration for competencies (4) selection by competencies, (5) competencies development; (6) performance evaluation by competencies and (7) career progression plan (Wong and Marijani, 2020).

Competency mapping identifies key knowledge, being an input in the processes of Recruitment and Selection, Training and Development, Evaluation and Performance Management, and Career Progression (Pena Brandão, 2007; Sanghi, 2007). Then, it is essential to integrate the competencies portfolio strategically into the different Human Resource Management processes (Berio and Harzallah, 2005; Rani, Priyadarshini and Dave, 2012). Therefore, knowledge and skills management is increasingly essential for innovative organizations and can be considered critical to sustaining a strategic advantage (Corrêa, 2015).

Competency management on shop floor operators in industry 4.0

Industry 4.0 is an opportunity to increase a company's profitability by reducing repetitive functions, more ergonomics and new jobs, more specialized people, interactive human and technology collaboration, productivity, work-life balance, and smart assistance systems (Oesterreich and Teuteberg, 2016; Tjahjono *et al.*, 2017). So, with this new paradigm, companies will demand a different and more versatile employee with new skills and competencies. Therefore, companies must invest in the workforce by offering training to improve their competencies (B Chen *et al.*, 2017). However, in the Industry 4.0 scenario, other skills are needed to face the current challenges (Agolla, 2018).

While the need for low-skilled workers is under discussion, the demand for highly skilled labor for Industry 4.0 has been consistent in the literature, including non-technical competencies, such as problem-solving and decision-making skills (Chryssolouris, Mavrikios and Mourtzis, 2013)

Executives are increasingly more involved in projects and strategic decisions, having less time to manage their shop floor staff. Nevertheless, it is at this level where most of the value is created in manufacturing companies, so executives need to ensure that operators are more autonomous and empowered (Suzaki, 1993). Also, the employees have higher expectations about their jobs and need challenges to keep them motivated. Thus, new skills should be developed to enhance the potential of these workers, promoting their involvement to achieve better results.

However, skills management programs require time and costs, and the operators are not available for training, especially in small and medium-sized companies. Thus, developing a transparent, integrated, and effective skills management methodology (Hertle *et al.*, 2016) is essential. Skill management approaches can be divided into two groups: Work-Based (training workshops, training centers, practice firms, or learning factories) and Work-Bound (usually carried out during the work process informally, i.e., without a formal learning framework). It should also be able to connect operators with problems to facilitate their involvement and development, as well as integrate skills development into daily tasks aligned with the challenges of industry 4.0 (Hertle *et al.*, 2015).

Synergies between quality management and knowledge management

The discussion around KM should focus on its impact on the organization's performance, therefore, companies need to exploit the existing and new knowledge, becoming more and more "learning organizations." Furthermore, it is necessary to implement methodologies that allow the systematizing of KM in the business models. QM could help since it is multidimensional, multidisciplinary, and embraces all organizational processes (Akdere, 2009).

KM is one of the QM´s key factors of QM, essential in process management and conducting a continuous improvement strategy. Bajaria, (2000) argues that KM is inseparable from QM approaches, however the development of knowledge through QM continues little explored and interrelated with human resource management (HRM). As such, KM and QM departments work independently, being important to deepen their synergies within organizations. The interest in QM and KM's synergies has been growing, some studies have focused on this relationship (Wilson and Campbell, 2018). Zhao and Bryar, (2001) analyzed the complementarity between KM and TQM, arguing that both promote an improvement cycle towards organizational excellence. Some authors argue that KM is a valuable tool to support quality initiatives (Wilson and Campbell, 2018). Moreover, Jaime *et al.*, (2006) defend that this relationship can be analyzed from four different perspectives:

- The integration of QM with KM;
- QM as KM support;
- The impact of KM on QM;

· KM and QM as support to achieve better results together.

Several QM frameworks have been evolving to deepen the integration of KM and QM in a more structured and systematic way, namely the Malcolm Baldrige framework (Baldrige National Quality Award Criteria), ISO 9001, and EFQM. The Baldrige Business Criteria for Performance Excellence framework (Baldrige Performance Excellence Program, 2021) is structured into two main categories: Organizational Profile; and Measurement, Analysis, and Knowledge Management. These two categories comprise another six additional interdependent categories: Leadership; Strategic Planning; Customer Focus; Workforce Focus; Process Management; and Result. Each category contributes to constructing a QM system suited to each organization. This framework highlights KM as a core category for providing a knowledge flow that all units and departments should share. Knowledge can be a key ingredient for the interconnection of all other categories, allowing the collection and data analysis, building information clusters and knowledge at all organizational levels (Akdere, 2009).

In September 2015 was released a new version of ISO 9001 to support QM System implementation. Among other significant changes, this publication includes for the first time a clause designated as "Organizational Knowledge," highlighting that an organization should determine "the knowledge necessary for its processes' (ISO, 2015 clause. 7.1.6). Consequently, companies must develop practices to identify, create, store, share and apply knowledge (Heisig, 2009). Moving on to a more detailed analysis, this clause includes the key elements of the knowledge management cycle:

- creation and acquisition: "Acquire or access the necessary additional knowledge"(ISO, 2015)
- capture and storage: “Knowledge shall be maintained” (ISO, 2015)
- distribution: "Knowledge shall be…made available as necessary” (ISO, 2015)
- application: “The organization shall determine the knowledge necessary for the operation of the QM system and its processes.” (ISO, 2015)

Additionally, this standard focus on a more comprehensive KM approach, namely implementing the 7.2 Competence, 7.4 Communication, and 7.5 Documented information clauses. Their implementation enhances the development of a strategic KM plan covering tactical and explicit knowledge management (ISO, 2015).

Also, the European Foundation for Quality Management Model (EFQM) has been described as an appropriate framework for improving organizational knowledge management. The EFQM has seven criteria organized in three dimensions (EFQM, 2020):

· The Direction: Purpose, Vision and Strategy; Organizational Culture and Leadership.

· The Execution: Stakeholder Involvement; Creating Sustainable Value; Driving Performance and Transformation.

· The results: Stakeholders' perceptions; Strategic and operational performance.

Several criteria in EFQM 2020 Model are directly addressed to KM, such as: 1.3 Understand the Ecosystem, Own Capabilities & Major Challenges; 3.2 People – Attract, Engage, Develop & Retain; 5 Driving Performance & Transformation; 5.4 Leverage Data, Information & Knowledge. These analysis certify the robust integration of KM in EFQM 2020 (Martín-Castilla and ´ Scar Rodríguez-Ruiz, 2008; EFQM, 2020) .

This diversity of frameworks and perspectives to interrelate QM and KM demonstrates the symbiosis between these fundamental areas in organizational development (Zetie, 2002). The authors Stewart and Waddell, (2008) argue that both KM and QM are very close and have a common denominator: Competitive advantage.

RESEARCH METODOLOGHY

As mentioned above, knowledge and skills management is increasingly essential for competitive organizations. Therefore, manufacturing companies need to develop their employees' competencies and make shop floor activities more attractive to the next generations. However, implementing Skills Management at an operational level is not always easy, being QM pointed as a facilitator. Thus, the main research questions are: What are the main synergies between QM and KM? How can this symbiosis support a competency management model?

To answer these questions, this research developed a singular case study in a ceramic sector company - Margres Ceramic Tiles- focused on an ongoing competency management project at the shop floor level. This company was selected for convenience since one of the researchers belongs to the project team (intrinsic case study). Data collection techniques were direct job observations, internal project documentation, procedures, and reports of the company's Integrated Management System (IMS).

The research's methodology is qualitative because its essence is the interpretive paradigm searching for a deep understanding. The object of analysis is formulated in terms of action and not behavior (Sharp, 2003). According to this paradigm, contrary to the positivist, reality and knowledge are constructed through communication and interaction between the researcher and participants (Mónico *et al.*, 2017). Case studies contribute to a deep and detailed understanding of complex real-life interactions and processes. This work is a descriptive study since it seeks to describe and understand the phenomena and solve concrete organizational problems.

A content analysis of each stage of competency management project was performed considering the main synergies between QM and KM identified in the literature review. The objective was to determine the main elements of QM and KM that facilitate developing a competency management model and its main stages. Finally, it is intended to describe some guidelines for developing knowledge at the shop floor level, given its importance of innovation and industry 4.0. Figure 1 summarizes the research design:

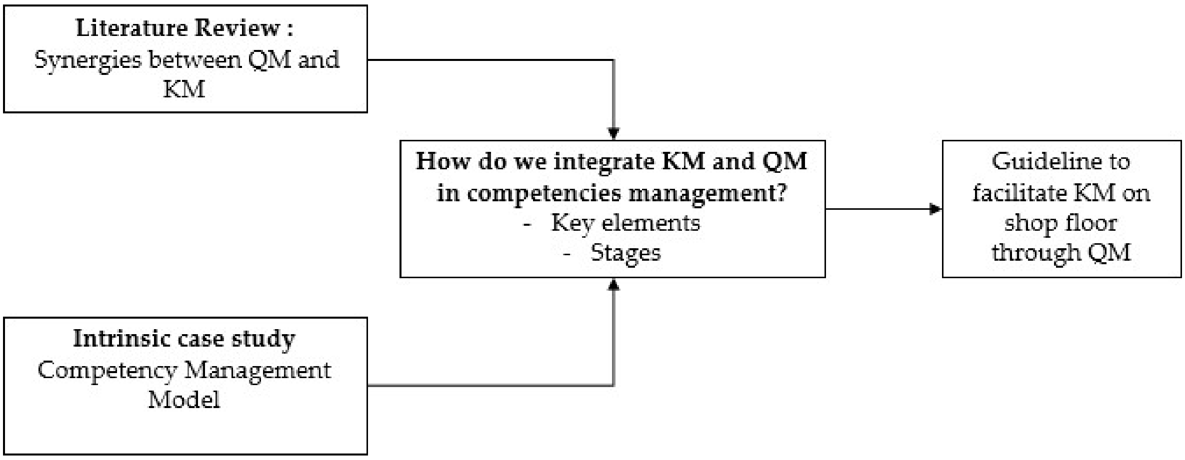

Figure 1 – Research Design

Case study - Competency Management Model

This case study was developed in Margres - Ceramic Tiles, which belongs to an Italian group, being one of the world's leading flat ceramic companies with two industrial sites in Portugal. This company has implemented an Integrated Management System (IMS) certified by ISO 9001:2015 and ISO 14001:2015. Furthermore, following its sustainability policy and recognizing that its employees are an essential asset for success, the company is committed to developing a strategy for involving and motivating them.

To this end, within the scope of its IMS continuous improvement principle, the company started a new project in September 2021 to develop and implement a competency management model. The main goal is to manage shop floor skills in different stages of human resources process management: Recruitment and Selection; Training and Development; Career Management; Performance evaluation; Career Progression; Remuneration Policy.

The project has been designed and developed in two layers in a pilot phase: the shop floor (13 production sections) and environmental and safety activities across all divisions. In this way, IMS's documented information and records allowed the understanding of the entire manufacturing process and the collecting of some information about skills.

Considering the project's internal documentation, the proposed competency management model consists of 4 main stages as described below:

Stage 1 – Identification of competencies: this phase aims to identify the key competencies by analyzing each productive sector, performing individual interviews, and conducting direct job observations. It also includes the analysis of the company's IMS information to:

- identify the records and transversal procedures;
- check outdated records;
- identify internal records not integrated into IMS.

Stage 2 – Description of competencies and standard works: detailed description of all the actions to correctly execute the competencies, highlighting the associated risks. In addition, setting indicators to measure performance and results to establish plan update levels.

Stage 3 - Competency matrix and assessment scale. It is a competency grid for each sector identifying the employee, main competencies, as well as the different levels:

- Level 1 - New admission / Does not perform
- Level 2 - In training (does it with supervision and follow-up)
- Level 3 – Apt (knows how to do it)
- Level 4 – Experienced (does it with quality)
- Level 5 – Instructor (does it with quality, solves problems and knows how to teach)

Stage 4 – Positioning matrix and actions: the last phase consists of positioning employees in the competency matrix and supporting strategic decisions. The manager will be able to carry out a concrete analysis of their employees and set the necessary actions to achieve the objectives.

In sum, this competency management model identifies and describes the specific skills by sector, allowing the employees positioning according to their autonomy level. The development of this project will enable the organization to carry out a detailed self-diagnosis knowledge management identifying necessary skills, namely technical skills (know-how), and transversal skills (attitude and behavior).

RESULTS AND DISCUSSION

According to the literature review, QM promotes organizational KM, given its multidisciplinary, systemic, process management approach and focus on continuous improvement. This work focuses on integrating KM in QM practices, making KM continuous and systematized in business models with added value for the organization and employees.

Several QM frameworks define knowledge as a key requirement. Specifically, the latest version of ISO 9001 published in 2015 highlighted the importance of "Organizational Knowledge" with the introduction of the new clause 7.1.6., as well as other requirements. Consistent compliance with these clauses allows the implementation of the main stages of the KM cycle: creation and acquisition; capture and storage; distribution; and application. This last step is essential because KM investments must be led to improve organizational performance. Also, this complementarity was identified in the structures of Malcolm Baldrige framework (Baldrige National Quality Award Criteria) and EFQM 2020.

Although the literature review sustains the complementarity of these two areas, few works point to concrete solutions to systematize KM practices through their QM models. The main contribution of this research comes in this direction, trying to answer the question, "How can this symbiosis support a competency management model?".

The competency management project presented points out a concrete solution. Thus, we tried to identify key elements at each stage and later understand how they could be interconnected, promoting the integration of QM and KM to leverage organizational performance. As shown in figure 2, each phase fosters essential QM practices, such as employees' awareness and commitment, effective management of skills, and continuous improvement. At the same time, each stage also integrates essential components of the knowledge management cycle, namely creation, capture, distribution, and application.

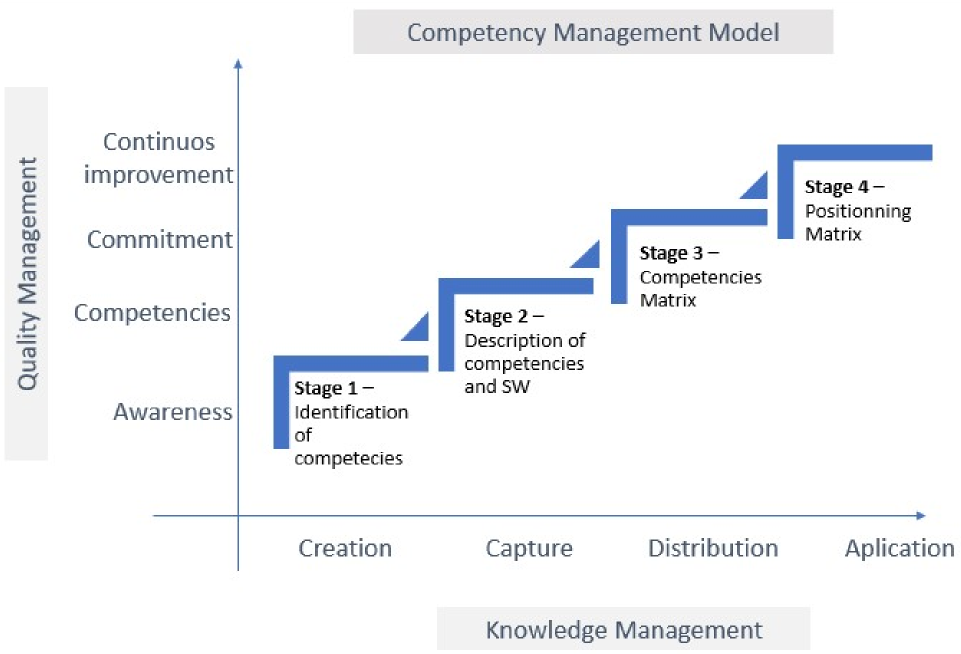

Figure 2 – Integrated Competency Management Model

The first stage integrates the key elements: Awareness (QM element) and Creation (KM element). This initial phase promotes knowledge by identifying the organization's critical skills, enhancing the operators' awareness by reflecting on the organization's expectations of its activities and the impact of its performance on organizational objectives. The IMS' documented information and the process management approach were essential elements in structuring this first step.

The identification of competencies should follow a comprehensive perspective. It should not be restricted only to technical or methodological skills but also to the attitudes necessary for adequate performance. It is even important that this phase promotes the creation of new knowledge integrating competencies aligned with the challenges arising from industry 4.0, both technical and transferable skills.

Stage 2 will play a decisive role in capturing this knowledge and transferring it to the organization's explicit knowledge. The SW intends to describe the competencies and detail all the actions to correctly execute the competencies, highlighting the associated risks. In this stage, we can interlink competency management, documented information records and procedures, and decisions supported on evidence (QM elements) with KM capture.

The focus of stage 3 is the competency matrix that allows the distribution (KM element) and assignment of the competencies to each operator. It also promotes employees' communication, involvement, and commitment (QM elements), as it identifies which skills should be improved and new skills to achieve by setting key performance indicators (KPI). Thus, the organization should focus on the clear interrelation of the defined competencies and the actions to achieve the organizational objectives.

Stage 4 emphasizes applying KM in favor of a continuous improvement strategy (QM element). It is expected that the results of this KM model will help managers make decisions in terms of critical competencies, training, and recruitment, as well as career progression plans. The effectiveness of these actions will be checked during the further competence assessment following a Plan -Do -Check -Act Cycle (QM element).

CONCLUSIONS

The literature review discussed the interrelationship between QM and KM and pointed it out as an emergent research area with different integration perspectives. However, recognizing this symbiosis is not enough; therefore, little research presents concrete solutions explaining how this compatibility can develop more effective KM models. Thus, this paper proposed a competency management model at the shop floor level, describing how its main stages interconnected KM and QM elements.

In this way, some guidelines are suggested to implement KM systematically.

- Integration of knowledge management practices in action plans associated with QM frameworks, namely QMS.

- Design a KM model that integrates the QM´s critical elements such as awareness, commitment, competency management, documented information, communication, PDCA cycle, process management, and continuous improvement.

- Design a KM model that includes the main phases of the KM cycle: creation and acquisition; capture and storage; distribution; and application.

- Promote the integration of QM and KM elements at each stage.

KM should help organizations retain information and make it a competitive advantage and a source of constant innovation, helping the organization improves quality and performance and adapt to industry 4.0 challenges.

ACKNOWLEDGMENT

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REPÚBLICA PORTUGUESA

FCT Fundação para a Ciência e a Tecnologia

REFERENCES

Agolla, J. E. (2018) 'Human Capital in the Smart Manufacturing and Industry 4.0 Revolution', *Digital Transformation in Smart Manufacturing*. InTech. doi: 10.5772/INTECHOPEN.73575.

Akdere, M. (2009) 'The Role of Knowledge Management in Quality Management Practices: Achieving Performance Excellence in Organizations', 11(3), pp. 349–361. doi: 10.1177/1523422309338575.

Andalib, M. S., Tavakolan, M. and Gatmiri, B. (2018) 'Modeling managerial behavior in real options valuation for project-based environments', *International Journal of Project Management*. Pergamon, 36(4), pp. 600–611. doi: 10.1016/J.IJPROMAN.2018.02.001.

Bajaria, H. J. (2000) 'Knowledge creation and management: Inseparable twins', *Total Quality Management*, 11, pp. 562–573. doi: 10.1080/09544120050007896.

Baldrige Performance Excellence Program (2021) *Baldrige excellence framework: Proven leadership and management practices for high performance*. U.S: Gaithersburg, MD: U.S. Department of Commerce, National Institute of Standards and Technology.

Berio, G. and Harzallah, M. (2005) 'Knowledge Management for Competence Management', *Journal of Universal Knowledge Management*, 1, pp. 21–28.

Bitencourt, C. (2004) 'A Gestão De Competências Gerenciais e a Contribuição Da Aprendizagem Organizacional', *Revista de Administração de Empresas*, 44(1), pp. 58–69.

Brandão, H. P. and Bahry, C. P. (2005) 'Gestão por competências: métodos e técnicas para mapeamento de competências', *Revista do Serviço Público*. Escola Nacional de Administracao Publica (ENAP), 56(2), pp. 179–194. doi: 10.21874/RSP.V56I2.224.

Chen, B *et al.* (2017) 'Smart factory of industry 4.0: Key technologies, application case, and challenges', *IEEE Access*, 6, pp. 6505–6519. doi: 10.1109/ACCESS.2017.2783682.

Chen, Baotong *et al.* (2017) 'Smart Factory of Industry 4.0: Key Technologies, Application Case, and Challenges', *IEEE Access*. Institute of Electrical and Electronics Engineers Inc., 6, pp. 6505–6519. doi: 10.1109/ACCESS.2017.2783682.

Chryssolouris, G., Mavrikios, D. and Mourtzis, D. (2013) 'Manufacturing systems: Skills & competencies for the future', *Procedia CIRP*. Elsevier B.V., 7, pp. 17–24. doi: 10.1016/J.PROCIR.2013.05.004.

Corrêa, G. C. (2015) 'Definição e desenvolvimento de competências: um paradigma no processo estratégico', *Estudos do CEPE*. APESC - Associacao Pro-Ensino em Santa Cruz do Sul, 0(41), pp. 103–116. doi: 10.17058/CEPE.V0I41.6294.

EFQM (2020) *EFQM 2020 Model- EFQM*. Available at: https://efqm.org/ (Accessed: 20 May 2022).

Heisig, P. (2009) 'Harmonisation of knowledge management-comparing 160 KM frameworks around the globe', *Journal of Knowledge Management*, 13(4), pp. 4–31. doi: 10.1108/13673270910971798.

Hertle, C. *et al.* (2015) 'The next generation shop floor management-how to continuously develop competencies in manufacturing environments'.

Hertle, C. *et al.* (2016) 'Recording Shop Floor Management Competencies - A Guideline for a Systematic Competency Gap Analysis', *Procedia CIRP*. Elsevier B.V., 57, pp. 625–630. doi: 10.1016/J.PROCIR.2016.11.108.

Holm, M. *et al.* (2014) 'Adaptive decision support for shop-floor operators in automotive industry', in *Procedia CIRP*. Elsevier B.V., pp. 440–445. doi: 10.1016/j.procir.2014.01.085.

Holm, M. (2018) 'The future shop-floor operators, demands, requirements and interpretations', *Journal of Manufacturing Systems*. Elsevier B.V., 47, pp. 35–42. doi: 10.1016/j.jmsy.2018.03.004.

Huff-Eibl, R. *et al.* (2011) 'Competency-based hiring, job description, and performance goals: The value of an integrated system', *Taylor & Francis*, 51(7–8), pp. 673–691. doi: 10.1080/01930826.2011.601270.

Isik, Z. (2009) *Impact of corporate strengths/weaknesses on project management competencies*. Elsevier Enhanced Reader.

ISO (2015) *ISO 9001:2015 - Quality management systems -- Requirements.* Geneva, Switzerland: ISO.

Jaime, A. *et al.* (2006) 'FROM QUALITY MANAGEMENT TO KNOWLEDGE MANAGEMENT IN RESEARCH ORGANISATIONS', *International Journal of Innovation Management*, 10(2), pp. 197–215. Available at: www.worldscientific.com (Accessed: 14 April 2022).

Jashapara, A. (2004) *Knowledge management: An integrated approach*. Edited by Essex. England: Pearson Education.

Krijnen, A. (2007) 'The Toyota way: 14 management principles from the world's greatest manufacturer', *Action Learning: Research and Practice*. Informa UK Limited, 4(1), pp. 109–111. doi: 10.1080/14767330701234002.

Lyons, P. (2003) 'Constructivist skill charting: Towards a model of performance improvement', *Annual Meeting of the Decision Sciences Institute,* pp. 751–756.

Martín-Castilla, J. I. and ´ Scar Rodríguez-Ruiz, O. (2008) 'EFQM model: knowledge governance and competitive advantage', *Journal of Intellectual Capital,* 9(1), pp. 133–156. doi: 10.1108/14691930810845858.

Mavrikios, D. *et al.* (2013) 'On industrial learning and training for the factories of the future: a conceptual, cognitive and technology framework', *J Intell Manuf*, 24, pp. 473–485. doi: 10.1007/s10845-011-0590-9.

Mónico, L. *et al.* (2017) 'A Observação Participante enquanto metodologia de investigação qualitativa |', *CIAIQ 2017*, 3(July), pp. 724–733. Available at: https://proceedings.ciaiq.org/index.php/ciaiq2017/article/view/1447 (Accessed: 14 April 2022).

Oesterreich, T. D. and Teuteberg, F. (2016) 'Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for', *Computers in Industry*, 83, pp. 121–139. doi: 10.1016/J.COMPIND.2016.09.006.

Pena Brandão, H. (2007) 'Competências no trabalho: uma análise da produção científica brasileira', *Estudos de Psicologia*, 12(2), pp. 149–158.

Rani, R., Priyadarshini, G. and Dave, D. (2012) 'Competency-based Training Needs Assessment Model'. doi: 10.1177/0258042X13484834.

Sanghi, S. (2007) *The Handbook of Competency Mapping: Understanding, Designing and implementing competency models in organization*. doi: 10.4135/9788132108481.

Sharp, C. A. (2003) 'Qualitative Research and Evaluation Methods', *Evaluation Journal of Australasia,* 3(2), pp. 60–61. doi: 10.1177/1035719X0300300213.

Stewart, D. and Waddell, D. (2008) *Total Quality Management Knowledge Management: The fundamental component for delivery of quality*, *Total Quality Management & Business Excellence*. doi: 10.1080/14783360802227803.

Suzaki, K. (1993) *The new shop floor management: Empowering people for continuous improvement.* New York: Free Press.

Tjahjono, B. *et al.* (2017) 'What does Industry 4.0 mean to Supply Chain?', *Procedia Manufacturing*. Elsevier, 13, pp. 1175–1182. doi: 10.1016/J.PROMFG.2017.09.191.

Wilson, J. and Campbell, L. (2018) 'ISO 9001: 2015: the evolution and convergence of quality management and knowledge management for competitive advantage', *Taylor & Francis*. Routledge, 31(7–8), pp. 761–776. doi: 10.1080/14783363.2018.1445965.

Wong, S. and Marijani, R. (2020) 'Competency Definitions, Development and Assessment: A Brief Review', *International Journal of Academic Research in Progressive Education and Development*. doi: 10.6007/IJARPED/v9-i3/8223.

Zhao, F. and Bryar, P. (2001) 'Integrating knowledge management and total quality: a complementary process', in *6th International Conference on ISO-9000 and TQM*. Paisley.

Development of a predictive model of financial performance indicators for organizations with integrated management systems, supported in artificial neural networks

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STRUCTURED ABSTRACT

Purpose - Artificial neural networks (ANN) are efficient in dealing with complex problems, therefore, its use for the development of prediction methods of key performance indicators (KPI) can prove as a source of competitive advantage for companies. The objective of this work was to evaluate the use of ANN to perform financial KPI forecasts in companies that use Integrated Management Systems.
Design/methodology/approach - Using the Orbis Europe database, indicators were collected from companies that have certified Integrated Management Systems. Data of 50 Portuguese certified organizations was used.
The Palisade NeuralTools software was used to develop the Artificial Neural Networks (ANN). 3 Models were developed for the prediction of 10 indicators: Model A predicts the indicators of 10 companies (for 2018 and 2019) using their own results from 2010 to 2019; Models B predicts the indicators of two companies for 2019, using an average of the indicators from 2010 to 2019 data from various companies; and Model C predicts the indicators of two companies for 2019 using an average of the indicators from 2010 to 2018 data from various companies.
Findings – The interpretation of ANN was done through graphics and relative error analysis. The results were based on data provided by the software and analyzed through graphs and tables for each of the 3 predictive models.
A comparison was made between forecasts and actual values, which allows us to conclude that the results using the ANN are satisfactory, although some indicators have performed better in one model than in another.
It was also possible to conclude that the use of the studied predictive models can bring competitive advantages through the improvement of processes, since the ANN also calculates which variables had the most impact on the prediction of each indicator, thus providing better precision in decision-making.
Originality/value - This study demonstrates positive results in the use of Artificial Neural Networks for the development of a forecast model for financial performance indicators, aimed at companies that use integrated management systems.

Keywords: Quality Management, Integrated Management Systems, Artificial Intelligence

INTRODUCTION

Many organizations implement Integrated Management Systems (IMS) to improve their performance and meet the needs and expectations of various stakeholders. Improvements promoted by the integration of Management Systems in terms of efficiency, product or service quality and environmental performance have an indirect impact on an organization's financial performance (Psomas & Pantouvakis, 2015; Fresnerv & Engelhardt, 2004), and studies prove that IMS impact the sustainability and stability of a company (Stefano & Laux, 2017; Martí-Ballester & Simon, 2017). However, the understanding of whether this stability allows better estimation of future financial results has not yet been sufficiently explored.

The development of new technologies now opens the door to this study. In order to understand how to best apply Artificial Intelligence technologies at the service of quality-minded organizations, the authors of this article developed and tested a set of predictive models that allow estimating the business results of a certified companies. Similar studies using AI have been presented with efforts of predicting defects and more efficiently scheduling audits (Castka & Searcy, 2021). The objective of this article is to show that it is also possible to create a predictive model of performance indicators in companies that certify and promote the integration of their management systems.

While these predictions are just estimates, and may be affected by as yet unknown factors, the models used in this study have proven to work efficiently even in the past decade’s highly unstable environments. Thus, the result of this work must be seen in the very aspect of a IMS – providing indicators of the company's behavior and helping it to react as quickly as possible, both by updating data in real time and by simulating different scenarios.

METHODOLOGY

Artificial neural networks (ANN) are an efficient and globally consolidated methods to address complex problems. Therefore, the development of a method for forecasting key performance indicators (KPI) through data science and neural networks can help companies to predict their performance and, through that, make decisions to look for improvements (Peral, Maté, & Marco, 2017; Nara, Sordi, Schaefer, SchreiberBaierle, Sellitto, & Furtado, 2019).

ANNs are computing systems inspired by the biological neural networks that organize our brains. The neurons used in ANN are mathematical elements that process crucial information for the neural network. Figure 1 shows this neuron model, and shows how an artificial neuron receives a signal and then processes it: the inputs (Xi) multiplied by their weights (wi) are added to the biases (bi) through the additive junction; the information then passes through the activation function (f(.)), generating an output y(t) (Haykin, 2001).

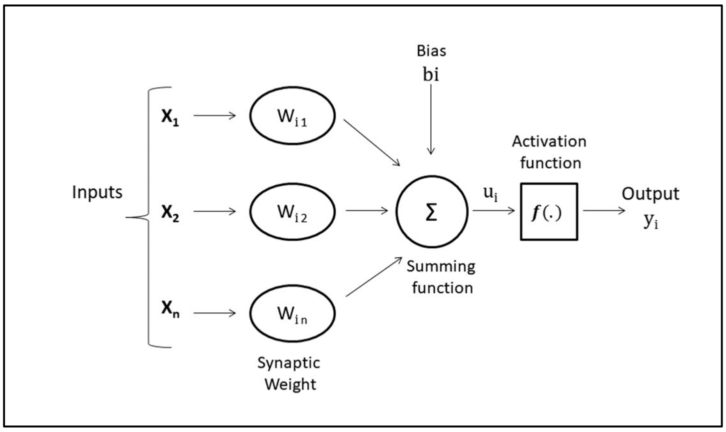

Figure 1: Model of a neuron. Adapted from Haykin (2001)

The realization of a good ANN requires reliable data. In this sense, the use of IMS certified companies is ideal. The purpose of IMS is to optimize and to unite information within a company so that all its processes are allocated within the same system and in the same environment, in the simplest possible way. IMS also intervene in the sustainability of the company and promote several characteristics that help to obtain greater reliability of data, such as the standardization of processes (Matias & Coelho, 2002; Vitoreli & Carpinetti, 2013), the use of centralized data (Salomone, 2008) and greater quality and security of information (Matias & Coelho, 2002; Salomone, 2008). By uniting several systems that are fundamental to an organization, IMS generate significant benefits that can result in cost savings and reduced use of valuable organizational resources (Almeida, Sampaio, & Santos, 2012). Notably, such characteristics are also fundamental for a good ANN (Schlegel, Buschmann, Ellerich, & Schmitt, 2020; Pipino, 2021).

DEVELOPMENT OF THE PREDICTIVE MODELS

Performance measurement should not only be used to control, but also as a factor of learning and improvement (Wegelius-Lehtonen, 2001; Bourne, 2008). Key performance indicators (KPI) inform leaders where it is possible to improve the organization's performance. Accordingly, there is great interest in understanding how well we can estimate the results of KPIs in the future, based on their real-time behavior and accumulated historical data.
To enhance the prediction of performance indicators in companies that use IMS, ANN were used as a tool to predict key performance indicators. Based on the exploratory nature of this investigation, three types of ANN were used:

Type A: ANNs were developed for 10 individual companies, predicting, for each company, the ten indicators for the years of 2018 and 2019. Prediction were made based on each company's own indicators for the years 2010 to 2019.

Type B: ANNs were developed with data from 50 different companies. In this case, through the data of several companies, an average of the indicators of all companies from 2010 to 2019 was used to predict the indicators of other companies for those same years.

Type C: as with Type B, ANN was developed with data from 50 companies. In this case, through the data of these companies, an average was carried out with the indicators from 2010 to 2018 to predict indicators related only to the year 2019 for two other companies.

DATA COLLECTION

Using the Orbis Europe database, indicators were collected from companies that have certified and integrated Management Systems.
Initially, a collection was carried out through the "Orbis Europe" database, which is a comparable data resource with information on more than 400 million companies and entities around the world (Bureau van Dijk, 2021). Portuguese companies that have IMS were selected in the database. Data of 50 Portuguese certified organizations was used, and 47 indicators from each company were considered (see appendix) to then feed the predictive models for ten key financial performance indicators:

Table 1: Key Financial Performance Indicators

Liquidity Ratio
EBITDA
ROE using Net income (%)
Gearing (%)
EBIT
Sales
ROA using Net income (%)
EBIT margin (%)
Profit margin (%)
Net income

DATA PROCESSING

The software used for data processing was NeuralTools. The software uses Probabilistic Neural Networks (PNN) and Generalized Regression Neural Networks (GRNN). The Probabilistic Neural Network is used in classification problems, where the user does not need to make any decision regarding the structure of the network. PNNs always have two hidden layers of neurons (Palisade, 2015). The Generalized Regression Neural Network requires the user needs to point out how many neurons the hidden layers must contain. This type of network admits fast predictions and has a greater reliability when the value of an independent variable deviates from the standard interval of the training set. In this case, the NeuralTools software allows using one or two hidden layers and assigning between 2 and 100 nodes per layer. This type of network can be used when the dependent variable is numerical or categorical (Palisade, 2015). For the neural networks used in this investigation, the option "search for the best network" was used. When this option is used, NeuralTools trains and tests a variety of network configurations until it generates the one that produces the best predictions for your data, the selection of the best network is performed automatically by NeuralTools based on the comparison of the error obtained by each network, that is, the network with the lowest percentage of error will be chosen by the software (Palisade, 2015). In this investigation, training, testing and prediction were performed simultaneously and the dependent variables, in all cases, were numerical. NeuralTools defaults to an error tolerance of up to 30%. If the trained value is within this margin of error, it is considered correct, if it exceeds this margin, it is considered incorrect.

RESULTS AND DISCUSSION

TYPE A PREDICTIVE MODEL

In type A, the individual forecast of 10 indicators was carried out for 10 companies that use IMS, totaling 100 Artificial Neural Networks.
ANNs were developed for 10 individual companies - which were coded A to J - and predictions were made for the years 2018 and 2019 for each company. Predictions were made based on each company's own indicators for the years 2010 to 2019. The predictions were then compared with the actual (real) indicators observed in the years 2018 and 2019.
As stated above the Neural tools software considers as "correct predications" those with an error under 30%. With the help of Matlab, graphs were drawn to compare the forecast and the actual results of the indicators (figures 2,3,4,5 and 6). Errors above 30% were identified with an arrow.

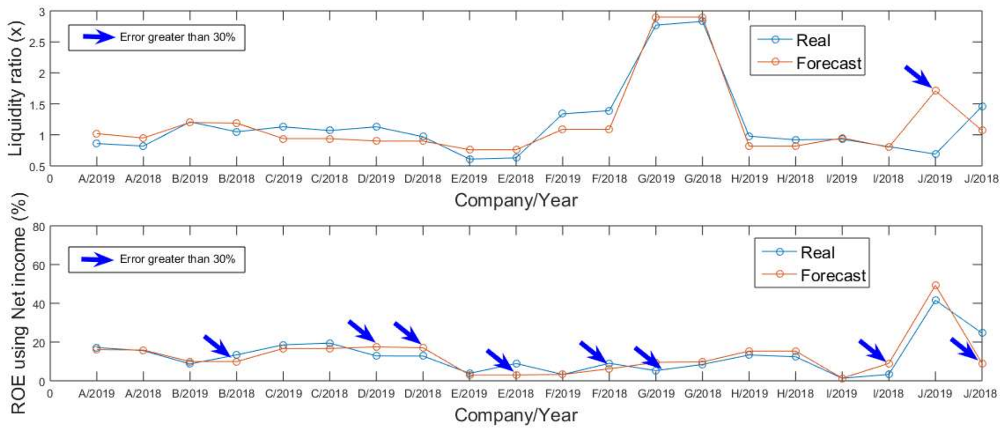

Figure 2: Comparison between the actual and forecasted value in the years 2018 and 2019, related to type A, of each company in relation to liquidity ratio and ROE using net income.

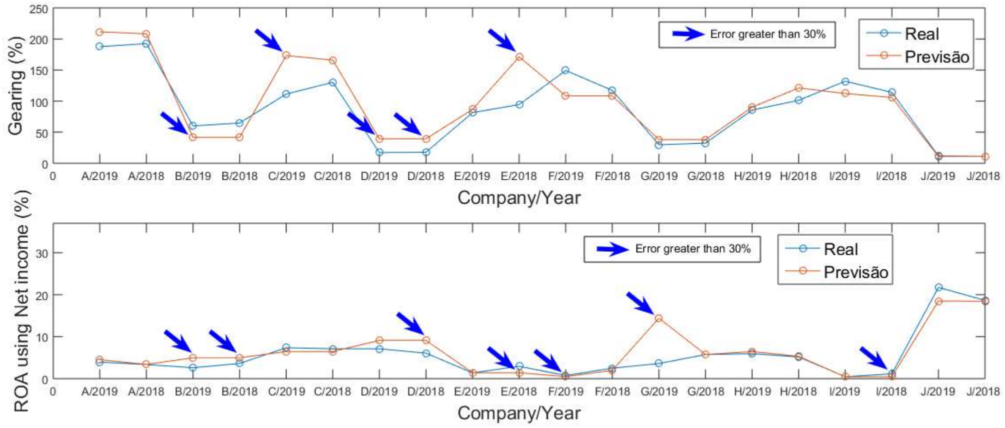

Figure 3: Comparison between the actual and forecasted value in the years 2018 and 2019, related to type A, of each company in relation to Gearing and ROA using net income.

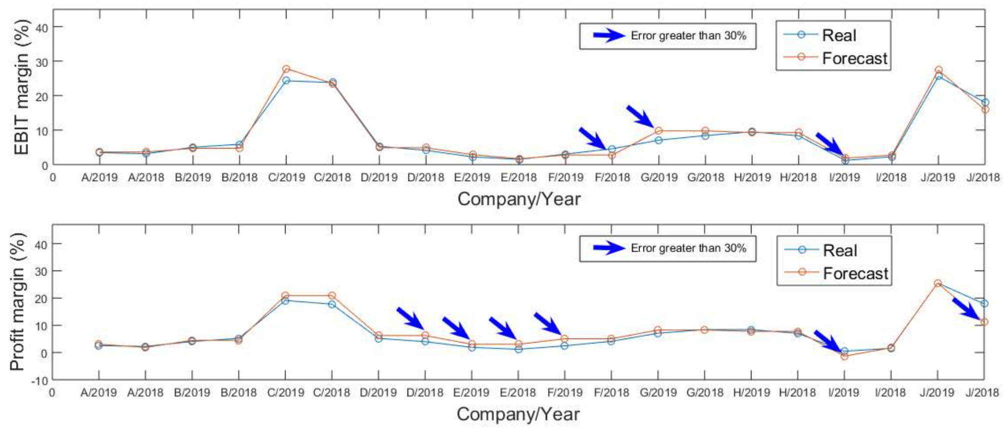

Figure 4:Comparison between the actual and forecasted value in the years 2018 and 2019, related to type A, of each company in relation to EBIT margin and Profit margin.

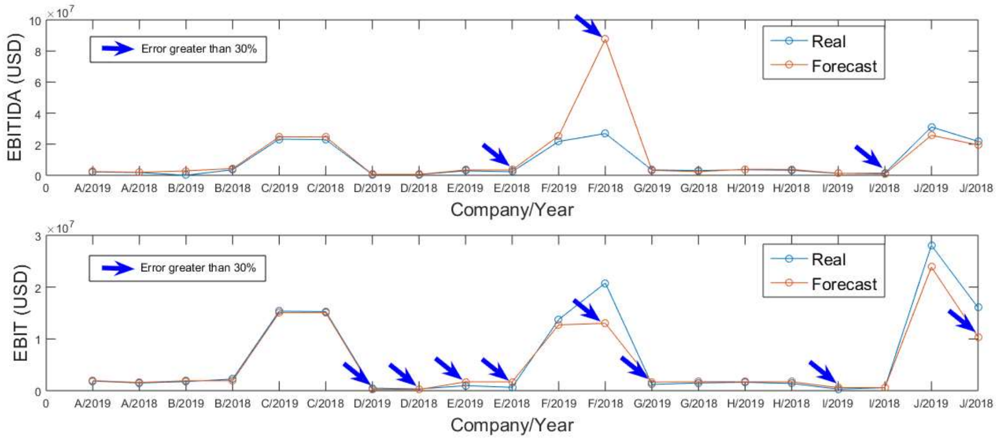

Figure 5:Comparison between the actual and forecasted value in the years 2018 and 2019, related to type A, of each company in relation to EBTIDA and EBIT.

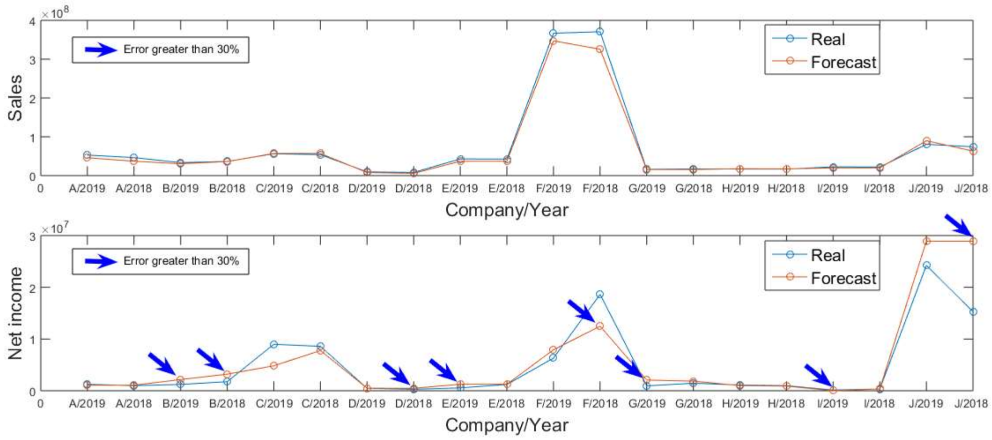

Figure 6: Comparison between the actual and forecasted value in the years 2018 and 2019, related to type A, of each company in relation to sales and net income.

Based on these results, it was possible to compose table 2, with the values of the relative errors of each indicator and the general average.

Table 2: Relative error of indicators related to the Type A predictive model.

INDICATOR	CORRECT FORECASTS (%)	CORRECT WORKOUTS (%)
Liquidity Ratio	95	93
EBITDA	85	83
ROE using Net income (%)	60	70
Gearing (%)	70	90
EBIT	60	60
Sales	100	100
ROA using Net income (%)	65	53
EBIT margin (%)	85	73
Profit margin (%)	70	53
Net income	55	57
Average	74,5	73

When analyzing table 2, it is possible to observe that there are indicators that obtained optimal forecasts and training and can be used by companies with greater reliability to predict their indicators, namely: liquidity index; EBITDA; sales; and EBIT margin that had an above average forecast percentage. Others were close to the average and have a lower reliability than those mentioned above, such as financial leverage, and profit margin. Of the indicators analyzed, four were below average: ROE using net income, ROA using net income, EBIT, and net income.

It is also possible to verify that the indicators liquidity index (x); sales (USD); EBIT margin (%); and profit margin (%) have a high reliability rate for the predictive model related to type A. At the same time, it was identified that for other indicators - ROE using net income (%); net profit (USD); ROA using net income (%); EBIT (USD); EBITDA (USD); and financial leverage (%) - the reliability is not as high as the indicators mentioned above, but they still maintain a good reliability and can be used in this predictive model.

TYPE B PREDICTIVE MODEL

For type B, 50 IMS certified companies were used. The same 10 indicators used for Model A were predicted. For each indicator, the results of two companies were predicted. 10 ANN were carried out - a network for each indicator - with the objective of comparing which type has the best efficiency and which indicators are more suitable for this predictive model. In this case, using data from several companies, an average was carried out with the indicators from 2010 to 2019 to predict the values of two other companies.

The correct forecasts thus are represented by scores of either 100% (the prediction for both companies presented errors below 30%) or 50% (the prediction for one of companies presented errors above 30%). These results may be seen in table 3. No cases occurred where the prediction offered errors above 30% in both cases (which would have meant 0% correct forecasts).

Table 3: Relative error of indicators related to the Type B predictive model.

INDICATOR	CORRECT (%)	FORECASTS	CORRECT (%)	WORKOUTS
Liquidity Ratio	50		90	
EBITDA	50		50	
ROE using Net income (%)	100		80	
Gearing (%)	50		50	
EBIT	50		40	
Sales	50		70	
ROA using Net income (%)	100		70	
EBIT margin (%)	100		80	
Profit margin (%)	100		90	
Net income	50		80	
Average	70		64	

In this model, it was possible to observe that the ROE indicators using net income (%); ROA using net income (%); EBIT margin (%) and Profit margin (%) obtained the best results and are more reliable to predict through Type B.

Bar graphs related to the 10 indicators used in the type B model were performed through figures 7 and 8.

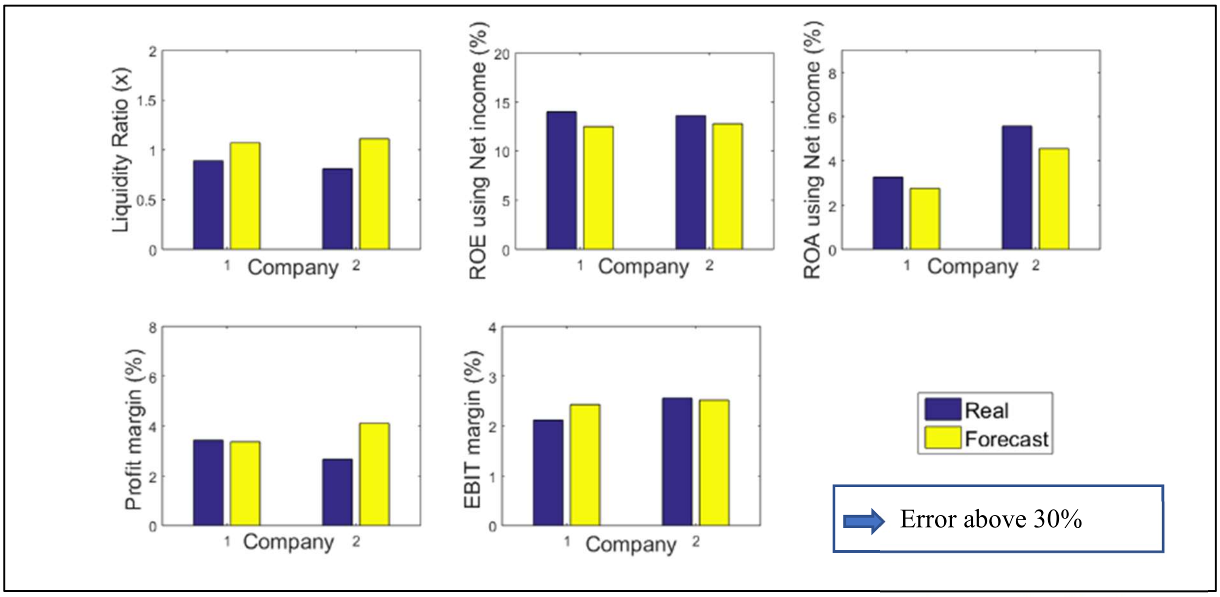

Figure 7: Comparison between actual value and forecast in type B neural network of indicators Liquidity ratio; ROE using net income; ROA using net income; Profit Margin; EBIT Margin

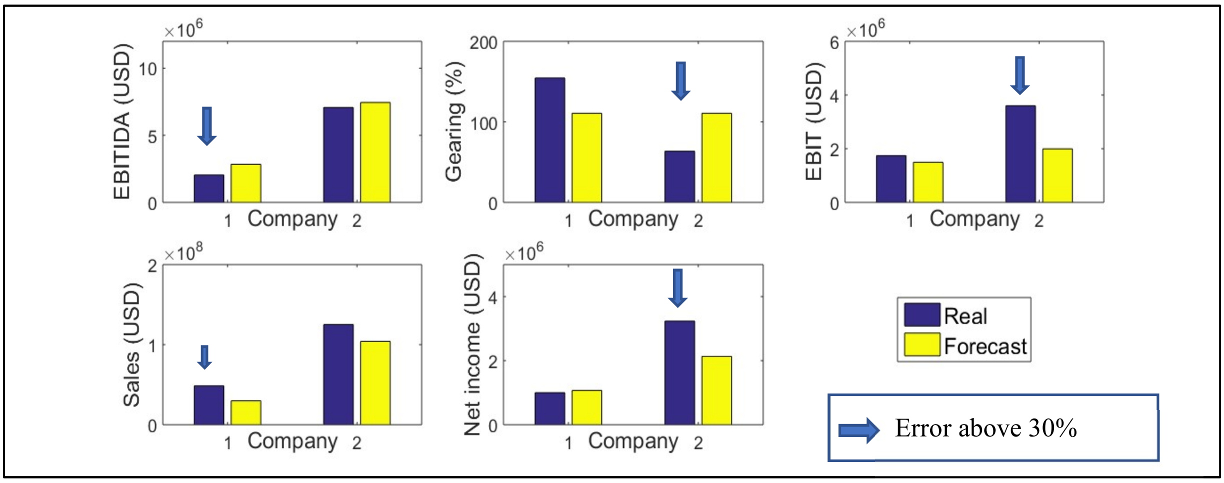

Figure 8: Comparison between the actual value and forecast in type B neural network of the indicators EBITDA; Gearing; EBIT; Sales; Net income.

TYPE C PREDICTIVE MODEL

For type C, the same 50 companies of the type B model were used. However, information from 2010 to 2018 was used, in order to predict only the indicators for 2019. For this, 10 ANN were carried out, one network for each indicator mentioned in table 4, with the objective of predicting which type has a better efficiency and which indicators are more suitable for this predictive model. Using data from the various companies, an average was carried out with the indicators from 2010 to 2018 to predict the values of two other companies in 2019.

As in type B, the forecast percentages for Type C were 50% or 100%, because for each indicator two companies were forecast. Thus, it was possible to observe that the indicators: liquidity ratio, ROE using net income, financial leverage, ROA using net income, EBIT margin, profit margin and net income obtained the best results and are the most reliable indicators to be predicted through the Type C (table 4).

Table 4: Relative error of indicators related to the Type C predictive model.

INDICATOR	CORRECT (%)	FORECASTS	CORRECT (%)	WORKOUTS
Liquidity Ratio	100		70	
EBITDA	50		40	
ROE using Net income (%)	100		70	
Gearing (%)	100		60	
EBIT	50		60	
Sales	50		40	
ROA using Net income (%)	100		70	
EBIT margin (%)	100		50	
Profit margin (%)	100		60	
Net income	100		40	
Average	85		56	

Bar graphs related to the 10 indicators used for type C were performed through figures 9 and 10.

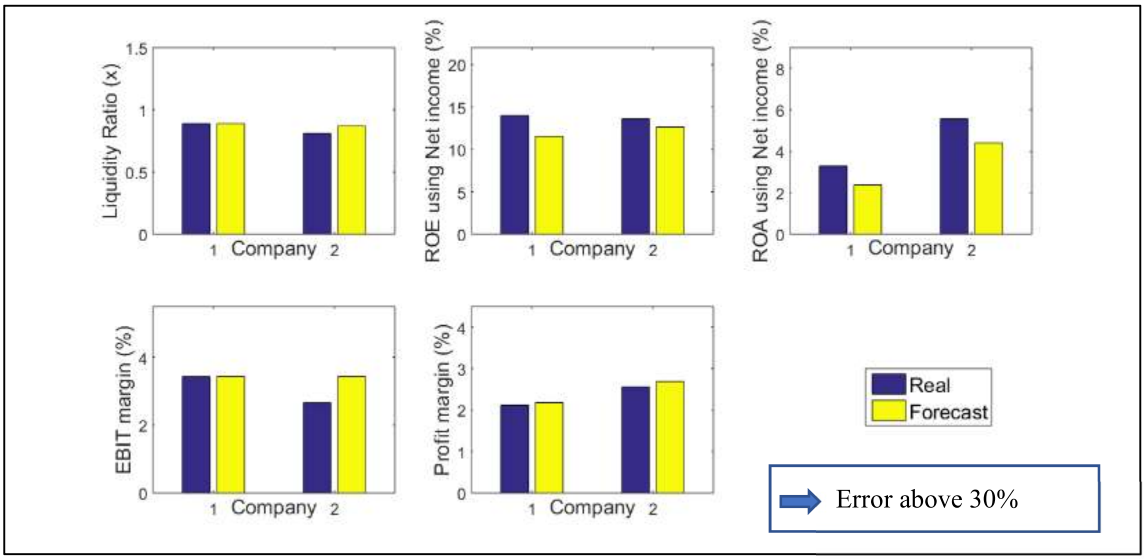

Figure 9:Comparison between actual value and forecast in type C neural network of indicators Liquidity ratio; ROE using net income; ROA using net income; Profit Margin; EBIT Margin

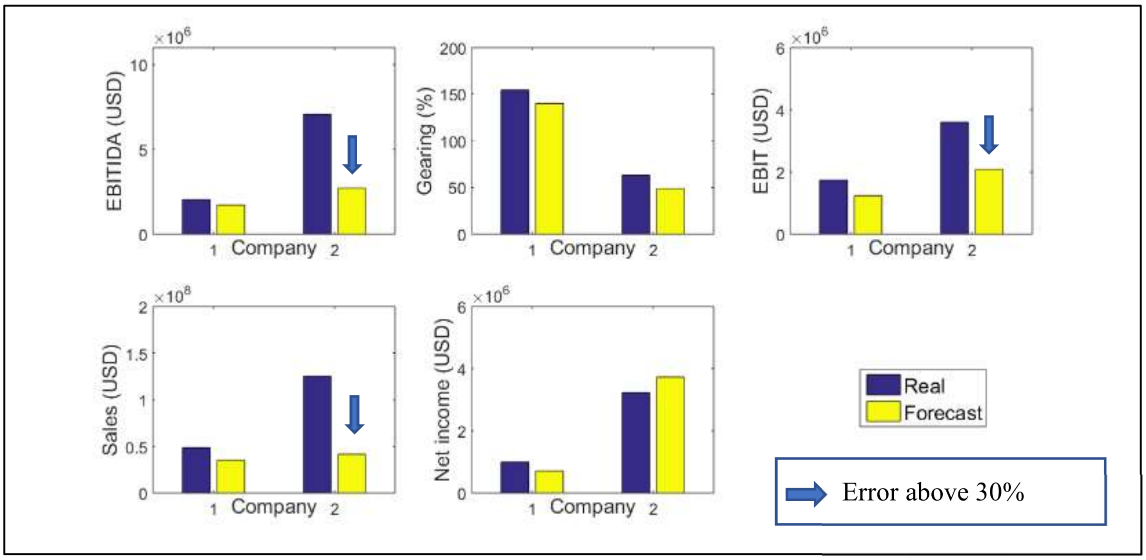

Figure 10:Comparison between the actual value and forecast in type C neural network of the indicators EBITDA; Gearing; EBIT; Sales; Net income.

CONCLUSIONS

This study demonstrates positive results in the use of Artificial Neural Networks for the development of a forecast model for financial performance indicators, aimed at companies that use integrated management systems. It was also possible to conclude that the use of the studied predictive models can bring competitive advantages through the improvement of processes, since the ANN also calculates which variables had the most impact on the prediction of each indicator, thus providing better precision in decision-making.

When analyzing the three types of predictive models, it is also possible to observe that each model has pros and cons according to the needs of each organization. Table 5 demonstrates which model is most appropriate for each indicator studied in this project.

Table 5: Comparison between the reliability of each predictive model in relation to the indicators.

RELIABILITY LEVEL OF EACH PREDICTIVE MODEL			
INDICATOR	**TYPE A**	**TYPE B**	**TYPE C**
Liquidity Ratio	High	Mean	High
EBITDA	Mean	High	Mean
ROE using Net income (%)	Mean	High	High
Gearing (%)	Mean	Low	High
EBIT	Low	Mean	Low
Sales	High	Low	Low
ROA using Net income (%)	Low	High	High
EBIT margin (%)	High	High	High
Profit margin (%)	High	High	High
Net income	Mean	Mean	High

Thus, and in view of the aforementioned facts, it is possible to affirm the possibility of predicting performance indicators in companies that use IMS through a predictive model using artificial neural networks (ANN) and, in this way, assess whether their indicators have a positive trend. or negative over the following months or years.

The statistics generated by NeuralTools and Matlab were used to generate graphs that helped in the analysis of the ANN. Through these analyses, it was concluded that the results generated by the predictive models carried out in this article have an excellent potential to predict indicators with a high level of reliability and thus help companies that use the IMS to know if their indicators have a growth trend or not, making it possible to improve the functioning of companies.

Naturally, there are some limitations to this work. First, only Artificial Neural Networks are used. While three model were developed to investigate the best fitting model for the problem under study, there are several other machine learning algorithms and neural networks model that could be developed to address the problem at hand. Second, while we focused on companies due to their potentially higher stability in terms of indicators, it with important to compare the results obtained in this work with those of a group of non-certified companies.

Accordingly, and in terms of future work, it will be critical to finish the ongoing work of this research group to compare and discuss the results obtained in a control group of organizations that do have Integrated Management Systems. Future research using different machine learning algorithms is also a clear opportunity.

REFRENCES

Almeida, J., Sampaio, P., & Santos, G. (2012). Integrated management systems–quality, environment and health and safety: motivations, benefits, difficulties and critical success factors.

Bourne, M. (2008). Performance measurement: learning from the past and projecting the future. *Measuring Business Excellence*.

Bureau vanDijk. (2021). Orbis—ComparePrivate Company Data—Bureau vanDijk. Recuperado 2de outubro de 2021,de Orbiswebsite: https://www.bvdinfo.com/en-gb/our-products/data/international/orbis

Castka, P., & Searcy, C. (2021). ARTIFICIALLY INTELLEGENT AUDITS. *Quality Progress*, *54*(9), 26-31.

De Oliveira Matias, J. C., & Coelho, D. A. (2002). The integration of the standards systems of quality management, environmental management and occupational health and safety management. *International journal of production research*, *40*(15), 3857-3866.

Fresner, J., & Engelhardt, G. (2004). Experiences with integrated management systems for two small companies in Austria. *Journal of Cleaner production*, *12*(6), 623-631.

Haykin, S. (2001). has a natural propensity for storing experiential knowledge and. *Nonlinear Dynamical Systems: Feedforward Neural Network Perspectives*, *21*, 1.

Martí-Ballester, C. P., & Simon, A. (2017). Union is strength: The integration of ISO 9001 and ISO 14001 contributes to improve the firms' financial performance. *Management Decision*.

Nara, E. O. B., Sordi, D. C., Schaefer, J. L., Schreiber, J. N. C., Baierle, I. C., Sellitto, M. A., & Furtado, J. C. (2019). Prioritization of OHS key performance indicators that affecting business competitiveness–A demonstration based on MAUT and Neural Networks. *Safety science*, *118*, 826-834.

Palisade. (2015). Manual do Usuário NeuralTools—Add-Inde Rede Neural para o Microsoft® Excel(Versão 7). Palisade Corporation.

Peral, J., Maté, A., & Marco, M. (2017). Application of data mining techniques to identify relevant key performance indicators. *Computer Standards & Interfaces*, *54*, 76-85.

Pipino, P. H. A. (2021).Sistema integrado de gestão empresarial (ERP) na construção civil. http://rdu.unicesumar.edu.br/handle/123456789/7361

Psomas, E., & Pantouvakis, A. (2015). ISO 9001 overall performance dimensions: an exploratory study. *The TQM Journal*.

Salomone, R. (2008). Integrated management systems: experiences in Italian organizations. *Journal of cleaner production*, *16*(16), 1786-1806.

Schlegel, P., Buschmann, D., Ellerich, M., & Schmitt, R. H. (2020). Methodological Assessment of Data Suitability for Defect Prediction. *Quality innovation prosperity/Kvalita Inovácia Prosperita*, *24*(2).
Stefano, N. M., & Laux, R. O. (2017). Sustentabilidade empresarial por meio do sistema de gestão integrada (SGI). *Sustainable Business International Journal*, (70).

Vitoreli, G. A., & Carpinetti, L. C. R. (2013). Analysis of the integration of normalized management systems ISO 9001 and OHSAS 18001: multiple case studies. *Gestão & produção*, *20*(1), 204-217.
Wegelius-Lehtonen, T. (2001). Performance measurement in construction logistics. *International journal of production economics*, *69*(1), 107-116.

Zimon, D., Madzik, P., & Sroufe, R. (2020). The influence of ISO 9001 & ISO 14001 on sustainable supply chain management in the textile industry. *Sustainability*, *12*(10), 4282.

Appendix

Table A – Indicators used for predicting the Key Financial Performance Indicators

1) Permanent assets;
2) Tangible fixed assets;
3) Other fixed assets;
4) Current assets;
5) Stock;
6) Debtors;
7) Other current assets;
8) Cash and cash equivalents;
9) Shareholder funds;
10) Capitals;
11) Other shareholder funds;
12) Non-current liabilities;
13) Long-term debt;
14) Current liabilities;
15) Creditors;
16) Other current liabilities;
17) Working capital;
18) Operating revenue (turnover);
19) Sales;
20) Operating P/E [= EBIT];
21) Financial price-to-earnings (P/E) ratio;
22) Financial expenses;
23) P/E before tax;
24) Taxation; 25) P/E after tax;
26) P/E for the period [= Net income];
27) Custody of employees;
28) Depreciation and Amortization;
29) Other operational items;
30) Cash flow;
31) Added value;
32) EBITDA;
33) ROE using P/E before tax (%);
34) ROA using P/E before tax (%);
35) ROE using net income (%);
36) ROA using net income (%);
37) Profit margin (%);
38) EBIT Margin (%);
39) Cash flow / operating income (%);
40) Turnover of liquid assets (x);
41) Collection period (days);
42) Credit period (days);
43) Current ratio (x);
44) Liquidity ratio (x)
45) Shareholder liquidity ratio (x);
46) Solvency ratio (asset-based) (%);

47) Gearing ratio(%).

The emergence of Industry 5.0: a bibliometric analysis

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STRUCTURED ABSTRACT

Purpose - Alongside the emergence of the fourth industrial revolution (Industry 4.0) and related concepts, such as internet of things (IoT), big data, digital transformation, cyber-physical systems (CPS), improved visualization, analytics and smart machine (among others) a novel approach evolved positing a more human centered revolution, focused on human machine collaboration and considering Society as a whole impacting and being impacted by such challenges - Industry 5.0 (I5.0). This paper aims to present a bibliometric analysis conducted on the topic of Industry 5.0, as the basis for a subsequent and forthcoming work of systematic literature review (SLR).

Design/methodology/approach - This article presents a bibliometric analysis performed by using the software Bibliometrix and Microsoft Excel, considering selected and relevant papers indexed to Scopus and Web of Science databases queried adopting the string “Industry 5.0”. This primary analysis helps to understand the scenario of I5.0, considering three main research questions: “Which are the boundaries between Industry 4.0 and Industry 5.0?”; “What is the definition of Industry 5.0?”; “Which are the main topics, authors and sources that have published on Industry 5.0?”.

Findings - After filtering, the analysis yielded a total of 103 bibliographic sources, accounting for 50% of them being journal articles, published during the past year. More than 40% of the papers have a strong relation to I5.0, and the results suggest the existence of several clusters of sub-topics that are being addressed by the academic researchers on this scientific domain.

Originality/value - This bibliometric analysis may help to disclose and uncover some patterns and outline some forthcoming research avenues.

Keywords: Industry 5.0, 5th Industrial Revolution, I5.0, Bibliometric Analysis.

Paper type: Literature review.

INTRODUCTION

Industry 5.0 is a novel approach that along with Industry 4.0 and related concepts has been the subject of a considerable and increasing number of researches. According to Breque et al. (2021), Industry 5.0 uses new technologies in order to provide prosperity in addition to growth and jobs, respecting sustainability while placing the worker's well-being as a central aspect. Industry 5.0 has its roots in Industry 4.0, the latter of which has focused on digitalization and AI-driven technologies to increase production flexibility and efficiency. Meanwhile, Industry 5.0 makes use of this advance achieved in Industry 4.0, but establishes three core elements: human-centric, sustainable and resilience.

It is important to raise some questions related to Industry 5.0, 5th Industrial Revolution and Society 5.0, given that this often generates doubts. Regarding the difference between Industry 5.0 and the 5th Industrial Revolution, Pessôa and Becker (2020) explain it using Industry 4.0 and the 4th Industrial Revolution. According to the authors, Industry 4.0 and the 4th Industrial Revolution are not exactly the same thing. While Industry 4.0 focuses on the industrial environment, the 4th industrial revolution expands Industry 4.0 concepts beyond the factory floor. They also complement that the term Industry 4.0 was defined at the Hannover Fair in 2011, while the 4th Industrial Revolution as well as the previous ones do not have a defined start date, considering that it is a gradual phenomenon. According to Breque et al. (2021), the concept of Industry 5.0 emerged after a meeting in 2020 with research and technology organizations as well as funding agencies across Europe and from that meeting a document defining Industry 5.0 was prepared by the European Commission. The concept of Society 5.0 was established in 2016 in an Industrial Federation in Japan. It seeks a balance between solving environmental and social problems allied to the economic aspect (Breque et al., 2021).

In Industry 4.0, the focus is on improving process efficiency, leaving aside the human cost resulting from this process optimization. Nahavandi (2019) states that in a few years, Industry 4.0 will face problems and some resistance due to the pressure to improve the number of jobs and he believes that Industry 5.0 will be the solution to this issue, uniting humans and machines in order to use even more the creative and intellectual capacity of the human being to increase the efficiency of the process through the combination of workflows with intelligent systems. In addition to the human issue, another highlight is the environmental issue, and the author points out that although there are initiatives that lead to this issue in Industry 4.0, this is not its focus, and Industry 5.0 brings this aspect as main point.

According to Xu et al. (2021), the Covid-19 pandemic created the need to rethink approaches and working methods in the face of the vulnerability of global supply chains, seeking to make industries more prepared for the future, being more resilient, centered on human and sustainable. For the authors, although many technologies used in Industry 4.0 can also be used in Industry 5.0, there are some technologies from Industry 5.0 that will need more attention such as bio-inspired technologies and technologies for energy efficiency, storage, and renewable energy. The authors add that the world is experiencing two revolutions side by side, Industry 4.0 is technology-driven and Industry 5.0 is value-driven. Industry 4.0 needs Industry 5.0 to remember essential social needs, value and responsibility as ultimate goals, while Industry 5.0 needs Industry 4.0 to drive technology solutions. Furthermore, it can be said that there is a techno-social revolution, where technology is seen as an enabling tool and social needs as the ultimate goal.

In view of all the points raised and the importance of it both for the academy and for the business environment and for society as a whole, the present research seeks to carry out a bibliometric analysis on the topic of Industry 5.0, considering three main research questions: “Which are the boundaries between Industry 4.0 and Industry 5.0?”; “What is the definition of Industry 5.0?”; “Which are the main topics, authors and sources that have published on Industry 5.0?”. This primary analysis helps to understand the scenario of I5.0 and is presented as the basis for a subsequent and forthcoming work of systematic literature review (SLR).

BIBLIOMETRIC ANALYSIS

This article presents a bibliometric analysis, method used to investigate, evaluate and monitor the state of certain topic over time, through a combination of quantitative and qualitative analysis (Fetscherin and Heinrich, 2015). Zupic and Čater (2015) discuss the relevance of bibliometric methods in handling the wealth of data existent nowadays, by filtering the important works, estimating their impact and discovering the underlying structure of a field. The authors emphasize that bibliometrics can be used as a complement to traditional methods of review such as extensive reading and synthesis.

This study follows a five-step procedure for conducting a bibliometric analysis, proposed by Zupic and Čater (2015): first the research question is defined and the appropriate methods to answer it are chosen; in second, the authors select the database; third, the bibliometric software is employed for analysis; fourth, the authors choose how the results will be visualized; and finally, the results are interpreted and described. Each step is described next, as follows: in “Planning the review” the authors define the research questions and describe how the questions will be answered, in terms of searching and filtering of papers; in “Data analysis” the authors present the software used to analyze the list of papers and its main visualization results; finally, in “Results and discussion” the research questions are answered.

Planning the review

Three review questions were developed, as a guide to the bibliometric analysis:

1. Which are the boundaries between Industry 4.0 and Industry 5.0?
2. What is the definition of Industry 5.0?
3. Which are the main topics, authors and sources that have published on Industry 5.0?

To answer the questions above, academic articles were searched in the Scopus and Web of Science databases, mainly due to the number and accessibility of papers found on them. Zupic and Čater (2015) highlight that data in bibliographic databases are the cause of some limitations of bibliometric methods, suggesting that The Social Science Citation Index (SSCI), accessible through Web of Science (WOS), is the most common source of bibliographic data and provides a really complete data. Scopus, owned by Elsevier, is also recommended by some bibliometricians as an alternative database.

"Industry 5.0" was used as the search string in "title, keywords and abstract", as the purpose of this review is to obtain general information about this new topic. None time window was used, since the aim is to identify when this topic starts to appear in the academic literature. These parameters led to 169 articles in the "Full Search", but some analysis still had to be made before selecting the papers, for this reason the authors established two filters. In the first filter, the duplicated papers were excluded and two inclusion criteria were analyzed: the language, excluding any paper that was not in English, Spanish or Portuguese; and the access, excluding the papers that do not have access information, such as DOI. The filtering led to a number of 118 articles, analyzed in the last filter: skimming the papers to classify them according their relation with Industry 5.0, following the scale described in Table 1.

Table 1 – Classification scale of paper's content

Scale	Relation with I5.0	Paper's content
0	No relation	It does not mention I5.0 or mentions it out of context
1	Very poor	It mentions I5.0 with focus on another concept
2	Poor	It relates the concept of I5.0 to some kind of tool or method
3	Fair	It uses the concept of I5.0 presenting some practical application
4	Strong	Its focus is I5.0 and/or adjacent concepts
5	Very strong	Its focus is clearly I5.0

From Figure 1 it is possible to see the selection and filtering process, that resulted in a total of 103 articles to be analyzed through bibliometric methods. From the classification, only the papers scale 0 (where I5.0 was not mentioned or it was mentioned superficially) were excluded; 42% of the papers have poor (scale 2) or very poor (scale 1) relation to Industry 5.0, 17% have a fair (scale 3) relation and 42% have strong (scale 4) or very strong (scale 5) relation, which means that the articles are clearly focused on I5.0and/or adjacent concepts. The classification process was made by two researchers, and were reviewed by the rest of the other two from the team, to guarantee consistency and quality of information, the basis to answer the research questions.

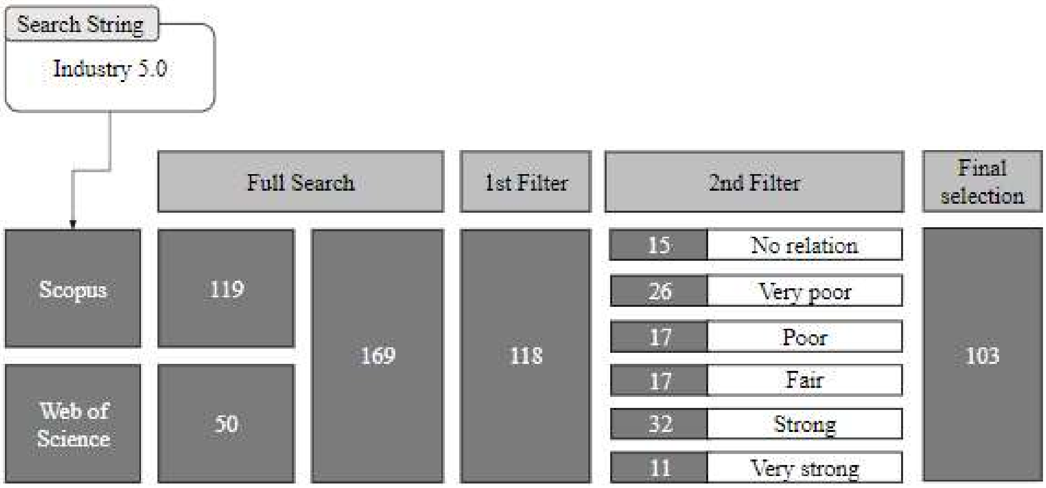

Figure 1 – Papers selection and filtering

Data Analysis

To perform the analysis, the authors opt for the use of Bibliometrix through its graphical interface Biblioshiny. Bibliometrix is a R tool package related to bibliometrics and scientometrics, being an open code tool capable of several quantitative analysis (Aria and Cuccurullo, 2017). As other many software tools available to help the bibliometric analysis of scientific literature, Bibliometrix takes raw bibliographic data exported from databases (preferably from the Web of Science), perform bibliometric calculations and calculate the similarity matrices between documents, authors, journals, words, and other items (Aria and Cuccurullo, 2017; Zupic and Čater, 2015). According to Zupic and Čater (2015), several studies report using Microsoft Excel to perform bibliometric calculations and export graphical visualizations of results. In this context, this data analysis consists of results both from Biblioshiny and Microsoft Excel, with information related to the documents, authors and sources.

After filtering 103 documents have been found between 2016 and 2022, spread between 81 different sources; 55% of the papers are in Scopus database, while 45% are in Web of Science. From Figure 2 it is possible to identify a growth tendency of the papers, reaching its peak in the past year, with 52 documents. It is important to mention that the drop in the number of publications in 2022 is due to the time window of the research, which was completed in January, meaning that this number is probably still growing.

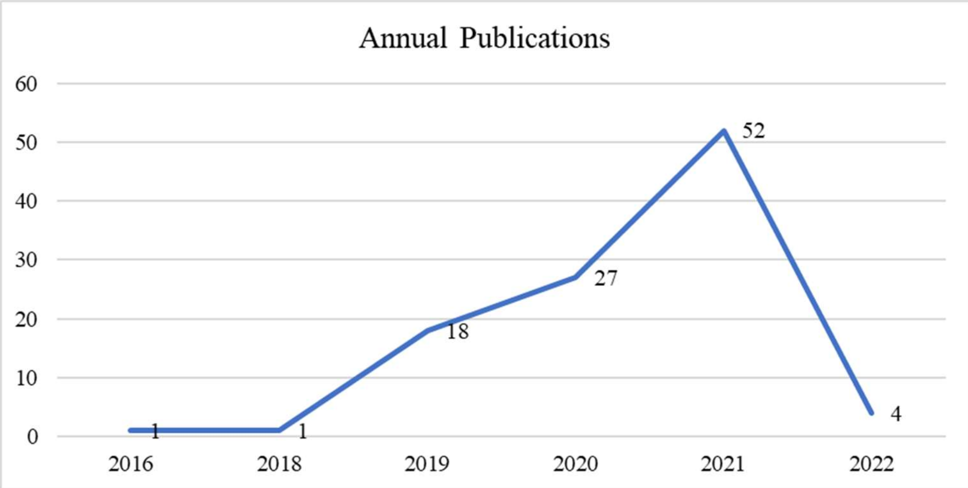

Figure 2 – Publications: Breakdown by Year

In terms of documents type, 56% refers to articles and 32% to conference papers, as shown in the Figure 3. The most cited is Özdemir and Hekim (2018) from Omics: A Journal of Integrative Biology, with 77 citations, followed by Nahavandi (2019) from the Sustainability journal, with 63 citations. Table 2 describes the list of the most cited documents and their respective sources, along with publication year and document type.

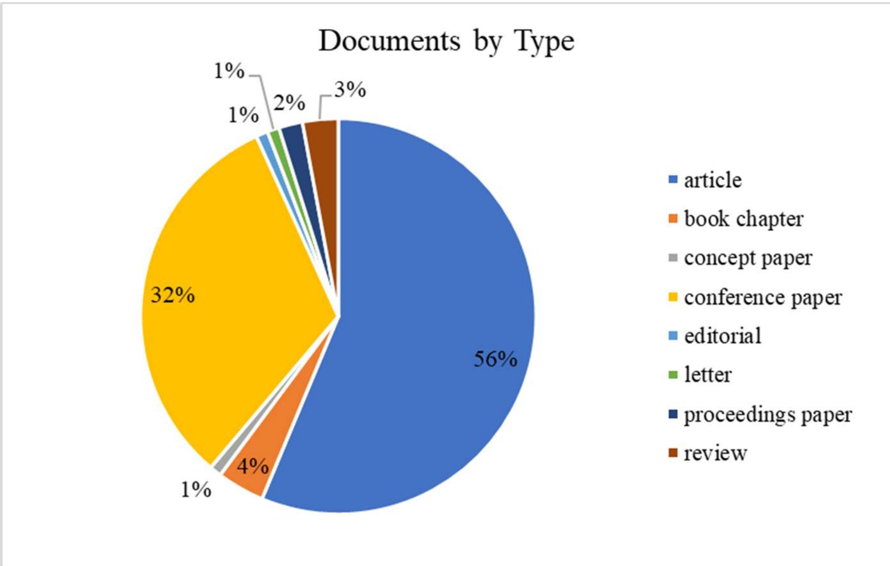

Figure 3 – Documents: Breakdown by Type

Table 2 – Most cited documents

Rank	Title	Authors	Source	Year	Document Type	Total Citations
1	Birth of Industry 5.0: Making sense of Big Data with Artificial Intelligence, "The Internet of Things" and Next-Generation Technology Policy	Özdemir V., Hekim N.	Omics: A Journal of Integrative Biology	2018	Article	77
2	Industry 5.0 - A human-centric solution	Nahavandi S.	Sustainability	2019	Concept Paper	63
3	Socio-technical perspectives on Smart Working: Creating meaningful and sustainable systems	Bednar P.M., Welch C.	Information Systems Frontiers	2020	Article	25
4	Industry 5.0: Potential applications in Covid-19	Javaid, M., Haleem, A., Singh, R.P., Haq, M.I.U., Raina, A., Suman, R.	Journal of Industrial Integration and Management	2020	Article	22
5	Industry 5.0 - The relevance and implications of bionics and synthetic Biology	Sachsenmeier, P.	Engineering	2016	Article	22
6	Value-oriented and ethical technology Engineering in Industry 5.0: A human-centric perspective for the design of the factory of the future	Longo, F., Padovano, A., Umbrello, S.	Applied Sciences	2020	Article	20
7	Critical components of Industry 5.0 towards a successful adoption in the field of manufacturing	Javaid, M., Haleem, A.	Journal of Industrial Integration and Management	2020	Article	17
8	Innovation in the era of IoT and Industry 5.0: Absolute Innovation Management (AIM) framework	Aslam, F., Aimin, W., Li, M., Rehman, K.U.	Information	2020	Article	15
9	Covid-19 and Hospitality 5.0: Redefining hospitality operations	Pillai, S.G., Haldorai, K., Seo, W.S., Kim, W.G.	International Journal of Hospitality Management	2021	Article	14
10	Consider the human work experience when integrating robotics in the workplace	Welfare, K.S., Hallowell, M.R., Shah, J.A., Riek, L.D.	14th ACM/IEEE International Conference on Human-Robot Interaction (HRI)	2019	Conference Paper	12
11	Walrasian Equilibrium-Based Multiobjective Optimization for Task Allocation in Mobile Crowdsourcing	Wang, Y., Cai, Z., Zhan, Z.-H., Zhao, B., Tong, X., Qi, L.	IEEE Transactions on Computational Social Systems	2020	Article	12
12	Prospects of Industry 5.0 in algae: Customization of production and new advance technology for clean bioenergy generation	Elfar, O.A., Chang, C.-K., Leong, H.Y., Peter, A.P., Chew, K.W., Show, P.L.	Energy Conversion and Management: X	2021	Article	10
13	Towards Fusion Energy in the Industry 5.0 and Society 5.0 Context: Call for a Global Commission for Urgent Action on Fusion Energy	Carayannis, E.G., Draper, J., Bhaneja, B.	Journal of the Knowledge Economy	2021	Article	8
14	Re-engineering process in a food factory: an overview of technologies and approaches for the design of pasta production processes	Massaro, A., Galiano, A.	Production and Manufacturing Research	2020	Article	7

The above-mentioned journal “Sustainability” (from the publisher MDPI) was the most relevant source in the list of papers, with 5 publications. **Erro! Autorreferência de marcador inválida.** presents a list with 11 sources with 2 or more publications, being on Top 5 the journals Sustainability (MDPI), Lecture Notes in Mechanical Engineering (Springer), Sensors (MDPI). IEEE Transactions on Industrial Informatics (IEEE) and Journal of Knowledge Economy (Springer Nature). The same analysis can be seen in accordance with the Bradford’s Law represented in Figure 4.

Table 3 – Sources relevance

Source	Publisher	Documents
Sustainability	MDPI	5
Lecture Notes in Mechanical Engineering	Springer	4
Sensors	MDPI	4
IEEE Transactions on Industrial Informatics	IEEE	3
Journal of Knowledge Economy	Springer Nature	3
Applied System Innovation	MDPI	2
IFIP Advances in Information and Communication Technology	Springer	2
Information Systems Frontiers	Springer Nature	2
International Journal of Supply Chain Management	Excelingtech Publishers	2
Journal of Industrial Integration and Management	World Scientific Publishing	2
OMICS: A Journal of Integrative Biology	Mary Ann Liebert INC.	2

This law classifies the sources into different “zones”, in which the core zone represents the group of sources which are mainly dedicated to the topic, in order to study a “decreasing productivity in the literature dispersion”, as defined by Bradford, and it keeps decreasing in the external zones.

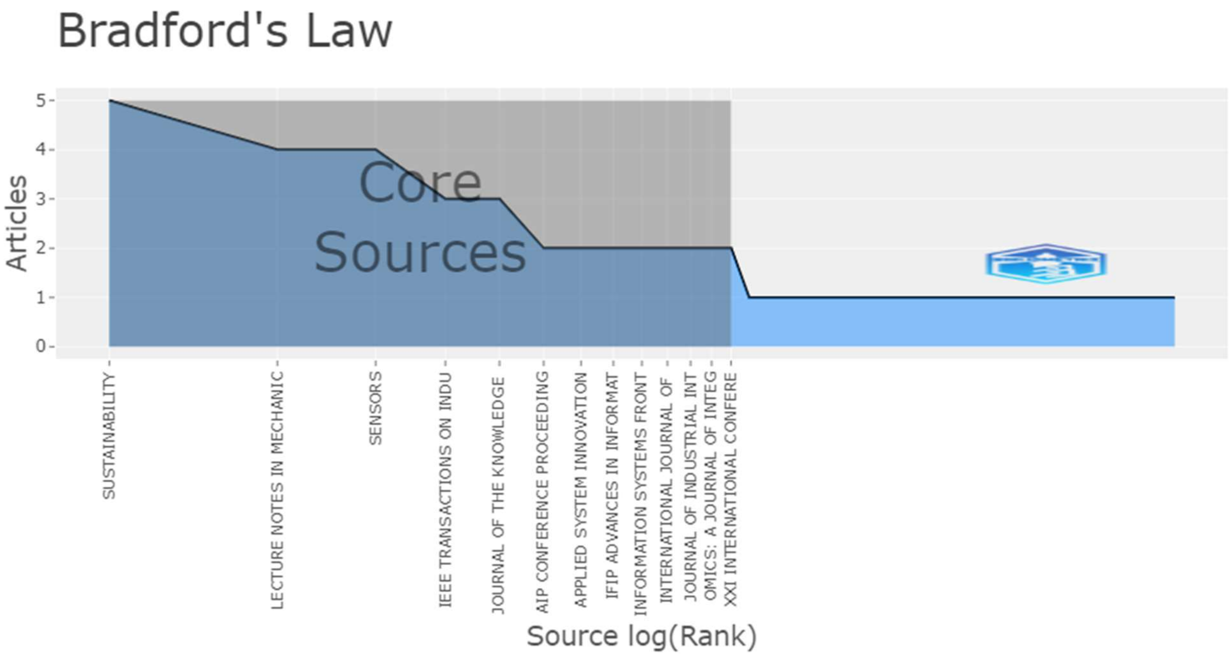

Figure 4 – Bradford’s Law: Core Sources

The main authors on this topic are listed in Table 4, following alphabetic order. It is also possible to see the countries of the authors' affiliations, from where it is important to highlight that, from the countries of the table, only Turkey, Ireland and Canada are not between the most frequent countries related in the Figure 5.

Table 4 – Authors relevance

First Authors	Documents	Affiliations' country
Carayannis, E.G.	3	United States
Demir, K.A.	2	Turkey
Doyle Kent, M.	2	Ireland
Fraga-Lamas, P.	2	Spain
Javaid, M.	2	India
Martynov, V.	2	Russia
Massaro, A.	2	Italy
Mihardjo, L.W.W.	2	Indonesia
Özdemir, V.	2	Canada
Rahman, N.A.A.	2	Malaysia

Figure 5 shows a Tree Map with the most frequent countries, based on authors' affiliations and by number of documents: 59% of the analyzed papers were published by authors from 7 countries; India is the most relevant, accounting for 15 documents, followed by Italy, with 11.

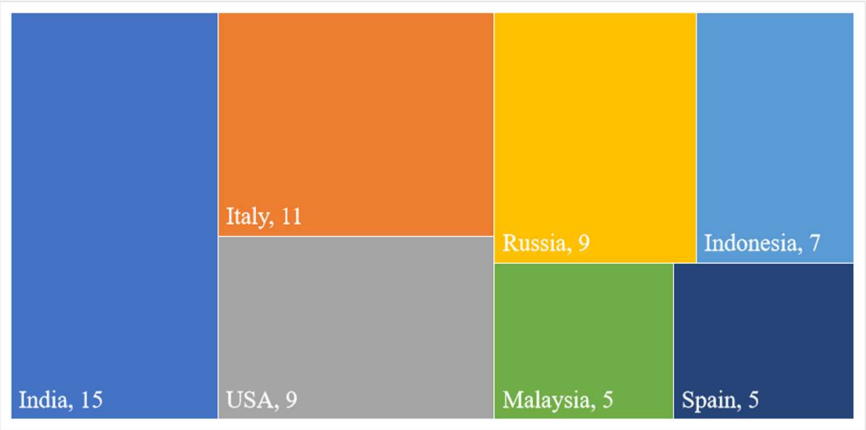

Figure 5 – Tree Map of countries

The keywords and abstract analysis indicate the most relevant words, as shown in Figure 6. It was expected that some concepts were more frequent once they are directly related to the search string (Industry 5.0). The meaning of I5.0 is also highlighted with the words "artificial intelligence", "sustainability" and "society 5.0". Although at first glance sustainability seems quite distant from I5.0, Breque et al. (2021) state that it is related to Industry 5.0 because in this new approach it is proposed that new technologies are used to provide prosperity in addition to growth and employment, respecting sustainability while placing worker welfare as a central aspect. The “0” appears as one of the most frequent word due the writing of the concepts in full and abbreviated form.

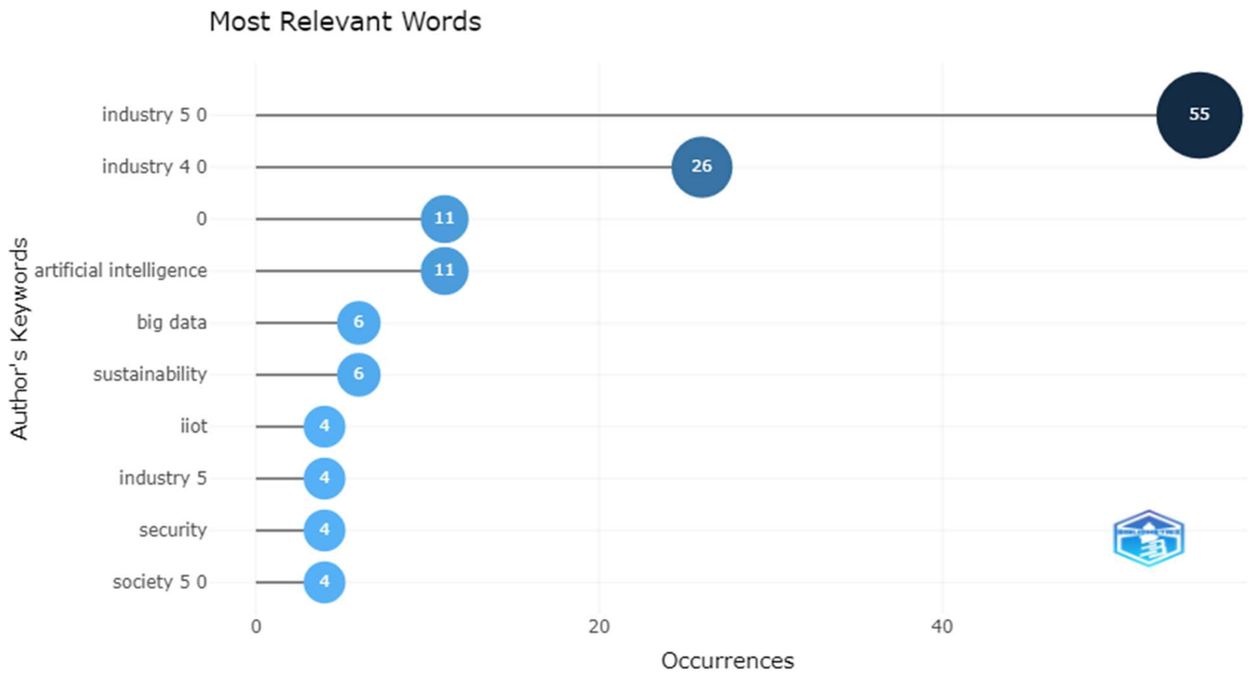

Figure 6 – Most relevant words

Figure 7 presents the most frequent words in a graphical visualization named Word Cloud, where the words size indicates their frequency. As pointed out by Figure 7 there is a set of concepts revolving and orbiting around two major concepts: I4.0 and I5.0. Figure 7 also suggests that there is not a disruptive approach towards Industry 4.0 from the perspective of Industry 5.0, i.e., this latter concept is considered a natural evolution from the former.

Figure 7 – Word Cloud

Finally, the thematic map (Figure 8) provides the clustering of terms identified in the documents, being the most relevant and frequent the purple and green clusters, that refer to data security and artificial intelligence. The concept of artificial intelligence refers to technologies widely used in I4.0, which leads one to believe that I5.0 has similar technologies used with a focus on the human factor. The pink cluster that refers to human factor is not among the most relevant ones, in terms of centrality, but it is frequent in the documents, in terms of density.

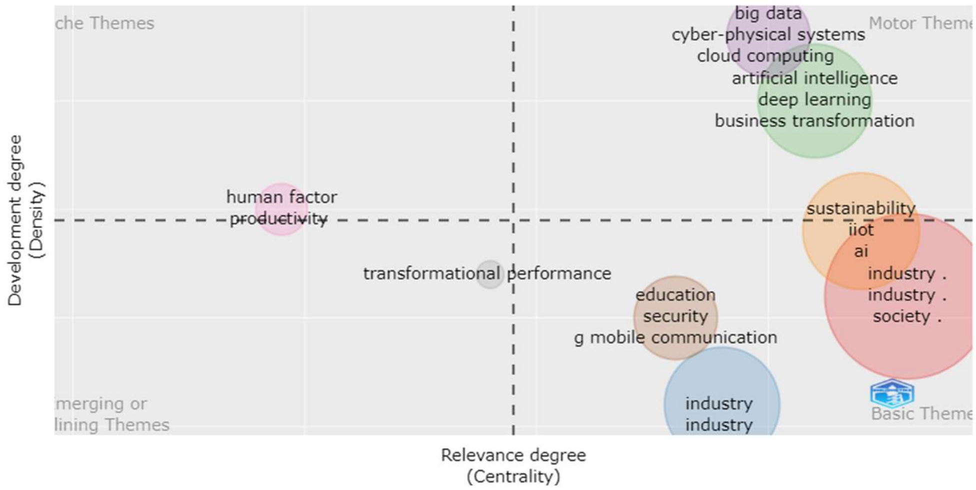

Figure 8 – Thematic map

In Figure 9 the thematic map is represented, with the most relevant author's keywords, affiliations and sources and how they are related. For example, from the University Kuala Lumpur in Malaysia, the most frequent words are "industry 5.0", "industry 4.0" and "sustainability", while the only used source for publishing is the International Journal of Supply Chain Management. This is expected due to the theme of this bibliometric analysis and because the already shown relation between sustainability and I5.0.

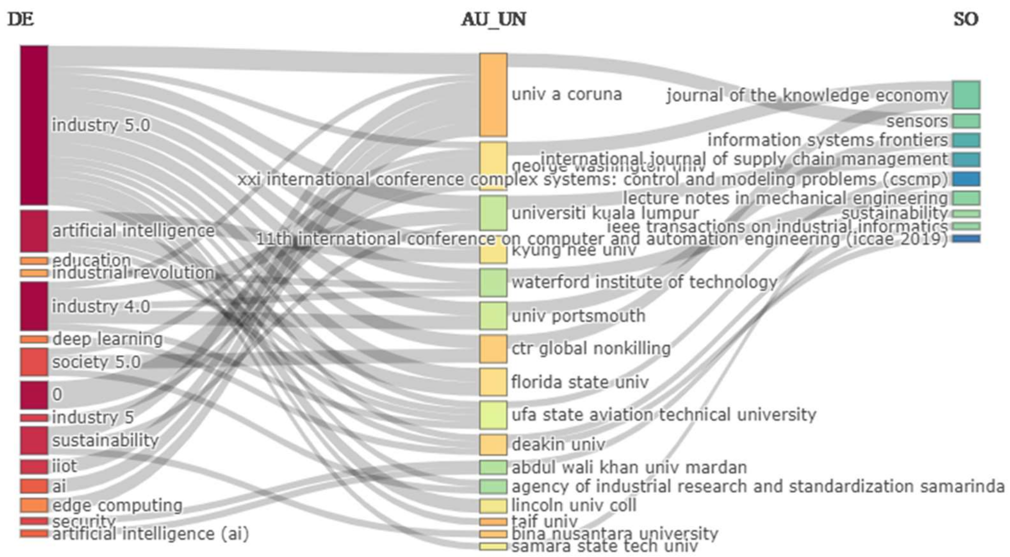

Figure 9 – Three-fields-plot (left side: authors' key words, center: authors' affiliations, right side: sources)

Results and discussion

The authors based on the bibliometric analysis previously described, in order to answer in more detail, the two first research questions: “Which are the boundaries between Industry 4.0 and Industry 5.0?”; “What is the definition of Industry 5.0?”. Javaid and Haleem (2020) performed a comparison between the main differences between Industry 4.0 and Industry 5.0. For the authors, Industry 4.0 focuses on digitization, while Industry 5.0 focuses on personalization. In addition, Industry 4.0 focuses on customization, while Industry 5.0 focuses on personalization; another point of differentiation is that Industry 4.0 focuses on digital use of data, while Industry 5.0 focuses on intelligent use of data; furthermore, Industry 4.0 provides better coordination between machine and information technology, while Industry 5.0 seeks close collaboration between men and machines; Industry 4.0 creates digitalization and automation through the application of information technologies, while Industry 5.0 globalizes the manufacturing system using advanced technologies.

According to Breque et al. (2021), a meeting was held in 2020 with research and technology organizations as well as funding agencies across Europe to discuss the concept of Industry 5.0 and from this meeting was develop a document prepared by the European Commission called “Industry 5.0: Towards a sustainable, human centric and resilient European industry”. Also, according to the same authors, the concept of society 5.0 was established in 2016 in an industrial federation in Japan. According to them, the way people guarantee their livelihood is linked to the way they build society, with the number 5 (5.0 society) coming from a very different time scale from that used for Industry 5.0. The first two societies correspond to pre-industrial periods. Society 3.0 corresponds approximately to the period that includes the 1st, 2nd and part of the 3rd industrial revolution. Society 4.0 is an evolution of a highly digitized version that contemplates the 3rd industrial revolution and comes to the present day. While the 5.0 society seeks to find a balance between the resolutions to environmental and social problems allied to the economic aspect.

In this context, Industry 5.0 makes use of the advance achieved in Industry 4.0, but establishes three core elements: human-centric, sustainable and resilience (Breque et al., 2021): the human-centric approach aims to place human interests and needs at the center of the production process, that is, instead of asking what can be done with the new technology, it is important to reverse the reasoning and ask what the new technology can do for humans. In addition, the focus on profit alone has proven unsustainable and it becomes increasingly urgent and important to include social and environmental issues in order to increase efficiency and maximize profits, while seeking to increase prosperity for all involved (investors, workers, consumers, society and the environment). With regard to resilience, a greater degree of robustness is sought in industrial production, avoiding interruptions.

The principles that guide Industry 5.0 are: mass customization (customization of products or services); cultural collaboration (removing borders between countries and regions helps new ideas emerge in order to make products better); customer at the center (customer aspirations become central focus); cyber-physical systems (building an intelligent system that contributes to meeting customer needs); and green computing, focused on renewable energy resources (Pathak et al., 2019). In Industry 5.0 it is necessary to consider how autonomous systems can incorporate ethical principles, so for I5.0 to occur, its three main elements (intelligent devices, intelligent systems, and intelligent automation) must merge with the physical world and act in cooperation with human intelligence. Robots are seen as collaborators rather than competitors, with the idea being to bring people back to the workplace and improve the efficiency of the process (Nahavandi, 2019).

In terms of regions of publication, in the research carried out by Madsen and Berg (2021), the countries that have published the most about Industry 5.0 are India and Turkey. Another interesting fact is that, according to the researchers, Germany, although it is the one that publishes the most about Industry 4.0, in the case of Industry 5.0 it has not stood out and is not even among the 10 countries that have the most publications on the subject. While from this bibliometric analysis, using the authors' affiliations 61% of the papers were published by authors from 8 countries, the first most frequent being India, followed by Italy.

CONCLUSION

Industry 5.0 is a novel approach that evolves positing a more human centered revolution, focused on human machine collaboration and considering society as a whole impacting and being impacted by such challenges. To understand I5.0 scenario the authors performed a bibliometric analysis by using Bibliometrix/Biblioshiny and Microsoft Excel, considering selected and relevant papers indexed to Scopus and Web of Science databases.

A total of 106 papers between 2016 and 2022 were analyzed in order to answer the research questions and to provide main information about the publications. 50% of the documents were published in the past year and 56% refers to article papers. India and Italy are between the most relevant countries in terms of published papers, along with the sources "Sustainability" (MDPI), Lecture Notes in Mechanical Engineering (Springer) and Sensors (MDPI). In terms of content, more than 40% of the documents present a strong relation to Industry 5.0, and the most frequent words found were "artificial intelligence", "big data" and "sustainability", which can be explained by the principles that guide Industry 5.0, mainly related to the customization of products or services, cultural collaboration, customer at the center, building an intelligent system that contributes to meeting customer needs and green computing, focused on renewable energy resources (Pathak et al., 2019).

The three research questions were answered by the authors according to the definitions found in the selected articles. As described in the previous section, Industry 5.0, 5th Industrial Revolution and Society 5.0 are closely related, but they are distinct concepts. Despite coming from Industry 4.0, the current themes shift the focus of I5.0 towards a junction of technology, sustainability and human factors. There is much more to be done in order to understand this new approach, but there are already many studies that help researchers and practitioners alike to understand and adopt Industry 5.0. This primary analysis may help to disclose and uncover some patterns and outline some forthcoming research avenues.

As future work the authors propose a systematic literature review (SLR), in order to provide useful insights related to I5.0. The main limitation of this work is related to the use of two databases, although they are very relevant and suggested as inputs for the use of bibliometric softwares, more databases could be used, as a suggestion for future works. It is also suggested that the research be redone in the future to analyze the evolution over the next few years. Among other future works suggestions, a systematic literature review (SLR) can be performed in order to provide useful insights related to I5.0, as well as research involving a better understanding of how the implementation of Industry 5.0 is taking place through case studies and surveys.

ACKNOWLEDGEMENTS

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REFERENCES

Aria, M. and Cuccurullo, C. (2017) “Bibliometrix: An R-tool for comprehensive science mapping analysis”, Journal of Informetrics, Vol. 11, pp. 959-975.

Aslam, F., Aimin, W., Li, M., Rehman, K.U. (2020) “Innovation in the era of IoT and Industry 5.0: Absolute Innovation Management (AIM) framework”, Information, Vol. 11.

Bednar P.M. and Welch C. (2020) “Socio-technical perspectives on Smart Working: Creating meaningful and sustainable systems”, Information Systems Frontiers, Vol. 22, pp. 281-298.

Breque, M., De Nul, L., Petridis, A. (2021) “Industry 5.0: towards a sustainable, human-centric and resilient European industry”, in European Commission, Directorate-General for Research and Innovation, Luxembourg, LU.

Carayannis, E.G., Draper, J., Bhaneja, B. (2021) “Towards Fusion Energy in the Industry 5.0 and Society 5.0 Context: Call for a Global Commission for Urgent Action on Fusion Energy”, Journal of the Knowledge Economy, Vol. 12, pp. 1891-1904.

Elfar, O.A., Chang, C.-K., Leong, H.Y., Peter, A.P., Chew, K.W., Show, P.L. (2021) “Prospects of Industry 5.0 in algae: Customization of production and new advance technology for clean bioenergy generation”, Energy Conversion and Management: X, Vol. 10.

Fetscherin, M. and Heinrich, D. (2015) “Consumer brand relationships research: A bibliometric citation meta-analysis”, Journal of Business Research, Vol. 68, pp. 380–390.

Javaid, M. and Haleem, A. (2020) “Critical Components of Industry 5.0 Towards a Successful Adoption in the Field of Manufacturing”, Journal of Industrial Integration and Management, Vol. 5, pp. 327-348.

Javaid, M., Haleem, A., Singh, R.P., Haq, M.I.U., Raina, A., Suman, R. (2020). “Industry 5.0: Potential applications in Covid-19”, Journal of Industrial Integration and Management, Vol. 5, pp. 507-530.

Longo, F., Padovano, A., Umbrello, S. (2020) “Value-oriented and ethical technology Engineering in Industry 5.0: A human-centric perspective for the design of the factory of the future”, Applied Sciences, Vol. 10.

Madsen, D.O. and Berg, T. (2021) “An Exploratory Bibliometric Analysis of the Birth and Emergence of Industry 5.0”, Applied System Innovation, Vol. 4.

Massaro, A. and Galiano, A. (2020) “Re-engineering process in a food factory: an overview of technologies and approaches for the design of pasta production processes”, Production and Manufacturing Research, Vol. 8, pp. 80-100.

Nahavandi, S. (2019) “Industry 5.0 - A Human-Centric Solution”, Sustainability, Vol. 11.

Pathak, P., Pal, P.R., Shrivastana, M., Ora, P. (2019) “Fifth Revolution: Applied AI & Human Intelligence with Cyber Physical Systems”, International Journal of Engineering and Advanced Technology, Vol. 8.

Özdemir V. and Hekim N. (2018) “Birth of Industry 5.0: Making sense of Big Data with Artificial Intelligence, ‘The Internet of Things’ and Next-Generation Technology Policy”, Omics: A Journal of Integrative Biology, Vol. 22, pp. 65-76.

Pessôa, M.V.P. and Becker, J.M.J. (2020) “Smart design engineering: a literature review of the impact of the 4th industrial revolution on product design and development” Research in Engineering Design, Vol. 31, pp. 175–195.

Pillai, S.G., Haldorai, K., Seo, W.S., Kim, W.G. (2021) "Covid-19 and Hospitality 5.0: Redefining hospitality operations", International Journal of Hospitality Management, Vol. 94.

Sachsenmeier, P. (2016) "Industry 5.0 - The relevance and implications of bionics and synthetic Biology", Engineering, Vol. 2, pp. 225-229.

Wang, Y., Cai, Z., Zhan, Z.-H., Zhao, B., Tong, X., Qi, L. (2020) "Walrasian Equilibrium-Based Multiobjective Optimization for Task Allocation in Mobile Crowdsourcing", IEEE Transactions on Computational Social Systems, Vol. 7, pp. 1033-1046.

Welfare, K.S., Hallowell, M.R., Shah, J.A., Riek, L.D. (2019) "Consider the human work experience when integrating robotics in the workplace", in 14th ACM/IEEE International Conference on Human-Robot Interaction (HRI), Daegu, South Korea, pp. 75-84.

Xu, X., Lu, Y., Vogel-Heuser, B., Wang, L. (2021) "Industry 4.0 and Industry 5.0—Inception, conception and perception", Journal of Manufacturing Systems, Vol. 61, pp. 530-535.

Zupic, I. and Čater, T. (2015) "Bibliometric Methods in Management and Organization", Organizational Research Methods, Vol. 18, pp. 429-472.

Assessing a customer complaint indicator: a case study in the automotive sector

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Introduction - Key Performance Indicators (KPIs) are used in many organizations to facilitate decisions and actions. A KPI life cycle is composed of four phases: design, implementation, use, and review. In the review phase, indicators may eventually be deleted, included, or replaced. The literature lacks analyses of the real improvement caused by the implementation and use of revised KPIs.

Purpose - This paper presents a real case of a reviewed KPI that was implemented in a leading company in the automotive electronics industry.

Methodology - The Methodology adopted was the Case Study.

Findings - The KPI that went through the review is related to customer complaints. Despite having overcome the limitation that triggered its creation, new shortcomings were perceived by management during the use phase. Three situations are presented to exemplify the limitations of previous and current indicators, concluding that the most critical drawback is present in both: the lack of a clear purpose. Therefore, assuming certain purposes, suggestions for improvement are proposed.

Keywords: Customer Complaint; Performance Indicator; Quality Management System.

Paper type: Case Study.

1. **INTRODUCTION**

A Key Performance Indicator (KPI) is a management tool that measures progress toward a project or process target and can be used in all kinds of organizations. When combined, groups of KPIs can form Performance Measurement Systems (PMS). Each management system, e.g., Logistics Management System, and Quality Management System (QMS), has a specific set of KPIs.

The QMS includes internal KPIs, which summarize compliance with engineering specifications, and external KPIs, which include customer complaint indicators (Sanchez-marquez *et al.*, 2020). If the QMS works well, both internal and external KPIs must reflect customer satisfaction. Indeed, quality control leads to the continuous evaluation and modification of the system to meet the changing needs of the customer (Mitra, 2016). Particularly, customer complaint indicators and their management processes are essential for avoiding and mitigating customer dissatisfaction.

While there are several studies on what constitutes the quality of a KPI concerning its support for decision-making and on how to assess this quality (Braz, Scavarda and Martins, 2011; Gutierrez *et al.*, 2015; Sousa, Nunes and Lopes, 2015), more empirical research is needed to describe and understand the variety of implementation processes that organizations follow in different contexts (Melnyk *et al.*, 2014). It is necessary to build an understanding of the precise definitions of existing KPIs, the rationales behind these, the data used, the limitations that users experienced with them, and ideas that people are working on to improve the existing system. In general, the literature lacks an analysis of real-life cases of practical problems encountered during the implementation and operability of KPIs (Van Camp and Braet, 2016).

From this background, this study aims to fill these gaps by reporting on and analyzing problems of implementation and use of a KPI through a Case Study. The study was conducted within a reference company in the automotive electronics industry, which is a Tier 1 supplier that works directly with a variety of Car Manufacturers. The case study focused on the customer complaint indicator, an external KPI, used in the QMS.

The rest of this paper is organized as follows. Section 2 presents a literature review on performance indicators, QMS, and the Complaint System in the Automotive Sector. Section 3 presents the case study, describes the analyzed KPIs highlighting their problems, and suggests improvements to overcome their limitations. In Section 4, the paper ends with conclusions and future research directions.

2. LITERATURE REVIEW

2.1 Performance Indicators

Performance indicators are used in many organizations to facilitate decisions and actions, monitor performance, identify areas that need attention, intensify motivation, improve communication, and strengthen responsibility (Melnyk *et al.*, 2014). Despite the great attention of scholars and practitioners to designing KPIs (Globerson, 1985; Neely *et al.*, 1997; Lohman, Fortuin and Wouters, 2004; Neely, Gregory and Platts, 2005; Lucianetti, Battista and Koufteros, 2019), there are also other vital processes in its life-cycle (Matos, Ensslin and Ensslin, 2020): implementing (Keathley-herring, 2017), using, and reviewing (Braz, Scavarda and Martins, 2011; Gutierrez *et al.*, 2015). These phases are represented in Figure 1.

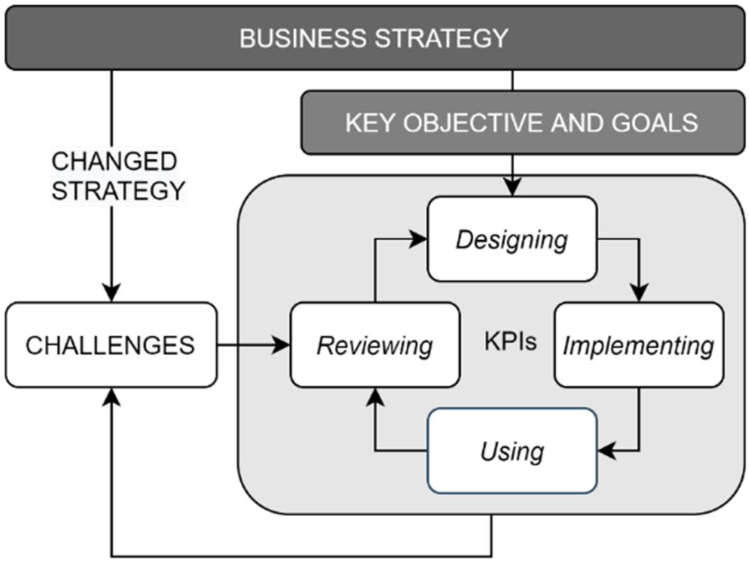

Figure 1 - The KPI life cycle. Source: adapted from (Almström et al., 2017).

The necessary conditions and characteristics that PMS must meet are still a challenge that must be properly addressed by researchers (Goshu and Kitaw, 2017). Nevertheless, some guidelines facilitate the design of appropriate KPIs, as shown in Table 1.

Table 1 - Characteristics of performance indicators.

Characteristics of performance indicators	**Description**
Derived from strategy with an explicit purpose	Performance measures need to be positioned in a strategic context, as they influence what people do (Neely, Gregory and Platts, 2005).
Clearly defined	Performance measurement must be easy to understand (Neely et al., 1996, 1997), and having clear and accurate syntax and semantics (Domínguez et al., 2019).

Provide timely and accurate feedback	The systems that exist inside or outside the company may be inadequate to provide accurate timely information necessary to make a good decision because of the inability to quantify or even assess the potential loss (Defeo, 2016).
Relevant	To keep performance indicators relevant, evolution management must be adopted considering KPI's traceability, modification, and change propagation (Domínguez et al., 2019).
Visual impact	Visual management techniques that integrate strategic and operational perspectives engaging people in a conversation on the strategy and performance of the organization should be applied (Bititci, Cocca and Ates, 2016).
Focus on improvement	The management team must identify improvement opportunities and prioritize changes based on the collective view on the maturity of their performance management practices (Bititci et al., 2015).
Precise	Organizations need to reflect the uncertainty of their systems and contextual factors in their performance measures to improve them (Sousa, Nunes and Lopes, 2015).
Acceptability by the user community	Imposition by top management for a strong focus on a selected set of indicators can have important motivational effects. However, if mid-level managers and employees do not sufficiently understand or agree to such prioritization, tensions and dissatisfaction are likely to arise (Jordan and Messner, 2012; Gutierrez et al., 2015).

About the implementation phase of KPIs, Neely et al. (1996) point out that the practical reasons frequently mentioned for implementing a PMS usually fall into five general categories: monitoring performance, identifying areas that need attention, and intening motivation, improving communication, and strengthening responsibility. On account of these issues, Gutierrez et al. (2015) point out some drivers to facilitate KPIs implementation: top management commitment, workshops to ensure common understanding among employees, and training sessions to promote proactive behaviour.

Within the use phase of the KPIs, "assessing the implementation of strategy'" and "challenging the strategic assumptions" are the two main subdivisions (Nudurupati, Garengo and Bititci, 2021). Likewise, as the competitive environment of a company changes, the KPIs must be adjusted (Almström *et al.*, 2017).

The KPIs can be revised on four levels: (1) revision of the strategy assumptions; (2) revision by changing KPI priorities, deleting, adding, and/or replacing them; (3) revising an individual KPI definition; (4) revising the KPI target value (Neely *et al.*, 2000; Bititci, Suwignjo and Carrie, 2001; Almström *et al.*, 2017). Challenges faced by companies that wish to improve their KPIs are related to decentralized reporting history; deficient insight into cohesion between metrics; uncertainty about what to measure; little communication between users and developers of performance measures;

fragmented IT infrastructure; and data availability limitations (Lohman, Fortuin and Wouters, 2004; Gutierrez *et al.*, 2015).

Many authors indicate that more empirical research must describe and understand the variety of implementation processes that organizations follow in different contexts (Braz, Scavarda and Martins, 2011; Melnyk *et al.*, 2014; Gutierrez *et al.*, 2015; Sousa, Nunes and Lopes, 2015). It is necessary to build an understanding of the precise definitions of existing KPIs, the rationales behind these, the data used, the limitations that users experienced with them and ideas that people are working on to improve the existing system, and how changes in information system changes can impact existing reports (Wouters and Sportel, 2005). In general, the literature lacks an analysis of real-life cases of practical problems encountered during the implementation and operability of the KPIs (Van Camp and Braet, 2016).

2.2 Quality Management and Complaint System in the Automotive Sector

QMS in automotive companies involves the entire process of design, procurement, manufacturing, and post-sales service, and each one of these phases must be planned to meet customer expectations (Mitra, 2016). While the predictability of the quality system can be understood as the ability to control customer satisfaction through internal KPIs, quality feedback is the ability of the system to recalibrate internal controls in an environment of continuous improvement, preventing future customer complaints (Sanchez-Marquez *et al.*, 2020).

A complaint management process is a systematic approach that includes all efforts connected to the detection of product failures and process flaws that enable an organization to identify and review possible weaknesses within its internal and external processes (Tuertmann *et al.*, 2016). Since establishing a complaint handling system is essential for addressing customer dissatisfaction and preventing similar problems from reoccurring, it is very important to standardize the complaint management system (S.Phabmixay, Rodríguez-Escudero and Rodríguez-Pinto, 2019).

The quality of a manufacturer's products depends not only on its own process/assembly quality but also on the quality of the components supplied by its suppliers (Hsieh and Liu, 2010), therefore, defects or potential defects may appear at any point of the supply chain. In other words, within a supply chain, there are risks associated with upstream suppliers (i.e. the sourcing process) and downstream customers (i.e. the delivery process) (Nel and Simon, 2020). Accordingly, companies at any point in the supply chain might eventually receive complaints. Figure 2 presents the flow of complaints and reporting in a supply-chain network consisting of multiple suppliers.

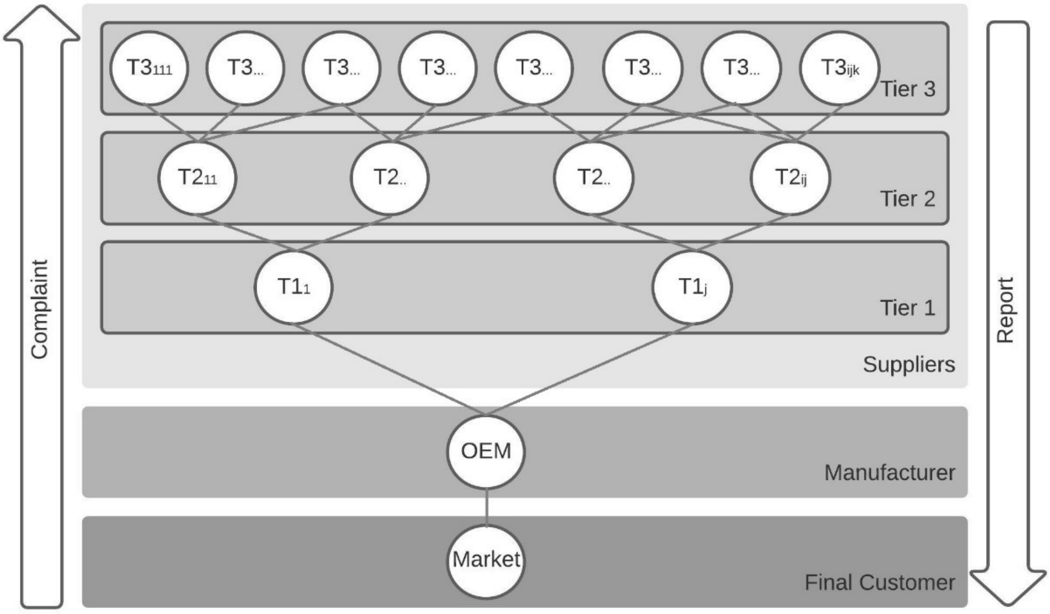

Figure 2 - Complaint Handling System in a supply-chain network consisting of multiple suppliers.

The Original Equipment Manufacturers' (OEM) focus is on designing cars, promoting cars, ordering from vendors, and assembling the vehicles. In the tier system, Tier 1 suppliers are companies that supply parts or systems directly to OEMs, usually working with a variety of car companies. Many firms supply parts that wind up in cars, even though these firms themselves do not sell directly to OEMs. These firms are called Tier 2 suppliers. The term Tier 3 refers to suppliers of raw, or close-to-raw, materials like metal or plastic. Tier 3 supplies to all levels - OEMs, Tier 1, and Tier 2 companies - as all need raw materials.

From the final customer up to the suppliers, the arrow in Figure 2 shows the flow of complaints. Any element of the supply chain can identify defects originating from its suppliers, for example, a Tier 1 can identify defects and formalize a complaint to Tier 2 companies.

In order to identify the root cause of a failure and to handle fault complaints, a standard procedure commonly used by the automotive industry is the 8D process (D for disciplines), installed by the German Association of the Automotive Industry (VDA) (VDA, 2017). When the 8D process is completed, a report is filled out to summarize how the root causes were determined and eliminated, and also what was done to contain the problem to prevent the root cause from happening again (Blank, 2014).

Comprehensive performance measurement is one of the main challenges in achieving data-based claims and fault management (Tuertmann *et al.*, 2016). Empirical studies on KPIs in this sense are needed and can bring many benefits to industries, as the use of customer satisfaction measures symbolically implies that the organization lacks processes that support their use in promoting improvements (Birch-Jensen *et al.*, 2020). Aware of the importance of customer satisfaction, this work, as an empirical study, evaluates current and previous established customer complaint KPI within a case study to be described in the next section.

3. CASE STUDY

The case study took place in a reference company (Company A) in the automotive electronics industry, which is a Tier 1 supplier working with a variety of OEMs. Located in Portugal, Company A is part of a large international organization with more than 3000 employees. The company has certifications for quality ISO 9001 and IATF 16949.

The research protocol was deployed in three major phases, as shown in Figure 3. The information sources were semi-structured interviews, data collected from the Enterprise Resource Planning (ERP), and internal documents of the company. The company where this work was done considers the data confidential, and the university research team signed a confidentiality agreement. For this reason, this paper does not specify the KPI values. Nevertheless, numerical hypothetical examples are given to discuss the problems with the KPIs. In Phase 3, suggestions are presented to overcome these limitations.

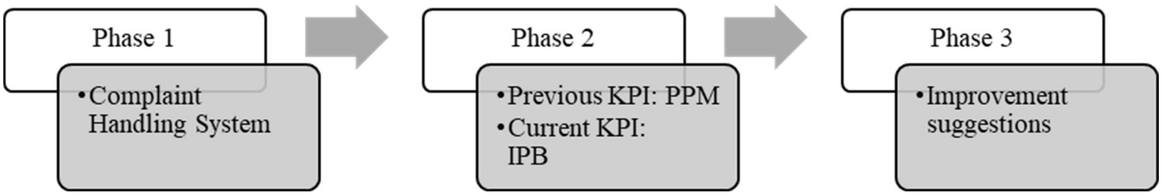

Figure 3 - Research protocol phases.

3.1 Phase 1: Complaint Handling System

Figure 4 presents a supply chain where a part labelled as Product 3 is provided by a Tier 2 to Company A (Tier 1 Supplier), who produces Product 2 as part of Product 1 to the OEM, that finally produces the car, which is then sold to the final customer.

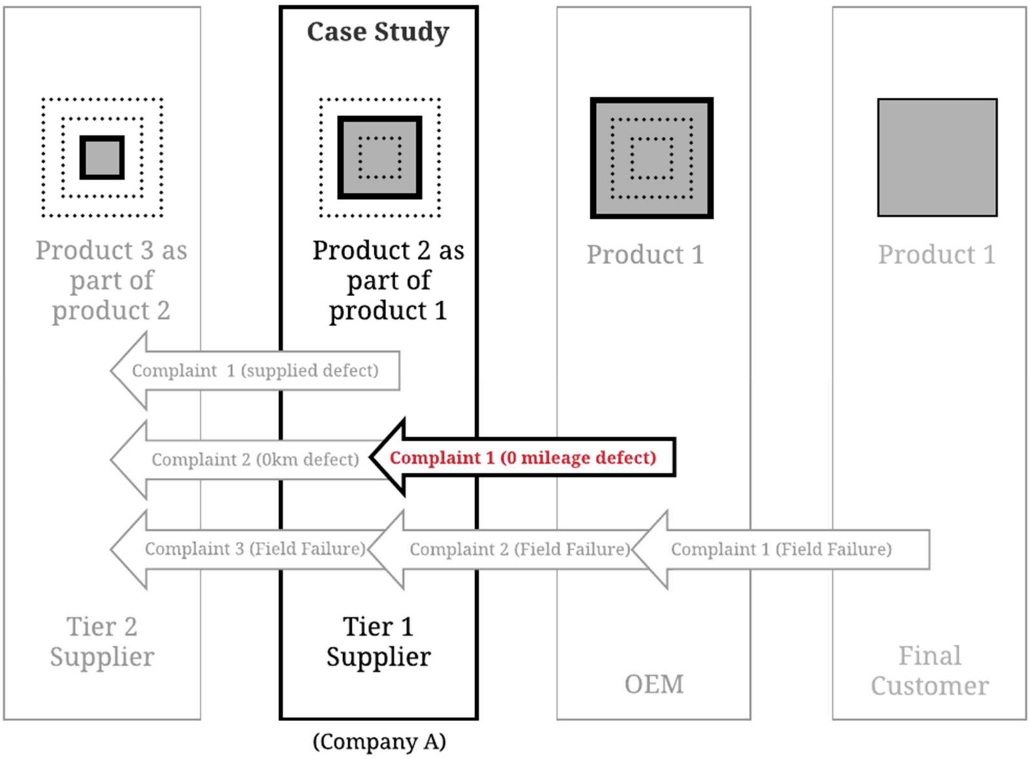

Figure 4 - Origin and types of complaints in the supply chain of Company A.

In Company A, external complaints are divided into two types according to their origin, which can be from the customers' factories (OEM) or the final customer (market). When a defective part is detected by the OEM, the claim counts as a "0 (zero) mileage defect", which can be found before the part is assembled in the car (for instance during an incoming inspection done at an OEM), or after it has already been installed. Complaints about uninstalled products are usually related to cosmetic defects, for example, labelling errors. These defects are rarer, as they are more easily detectable thorough inspection during production. When products are already installed in vehicles at OEM, they can reproduce failure modes that result in more critical defects, such as software or electronic problems. This paper analyses a KPI related to the complaint type "0 mileage defect", indicated in red in Figure 4.

The complaints handling process of Company A is based on the 8D method (Riesenberger and Sousa, 2010). The 8D method is applied for internal and external complaints. The timeline presented in Figure 5 shows important events of "0 mileage" complaints arranged in the order they happen, from the production date of a product, which eventually is found as defective, to the closed investigation of its failure root cause.

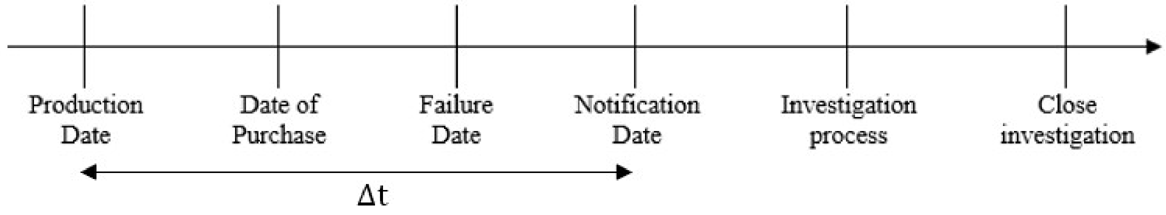

Figure 5 - Complaint handling process timeline.

Considering all the complaint data of Company A from January 2016 to March 2021, a total of 3364 complaints were recorded. Figure 6 is a histogram that presents the frequency of days between the Production Date and the Notification Date (Δt), showing that about 50% of the notifications happen eight weeks after the Production Date.

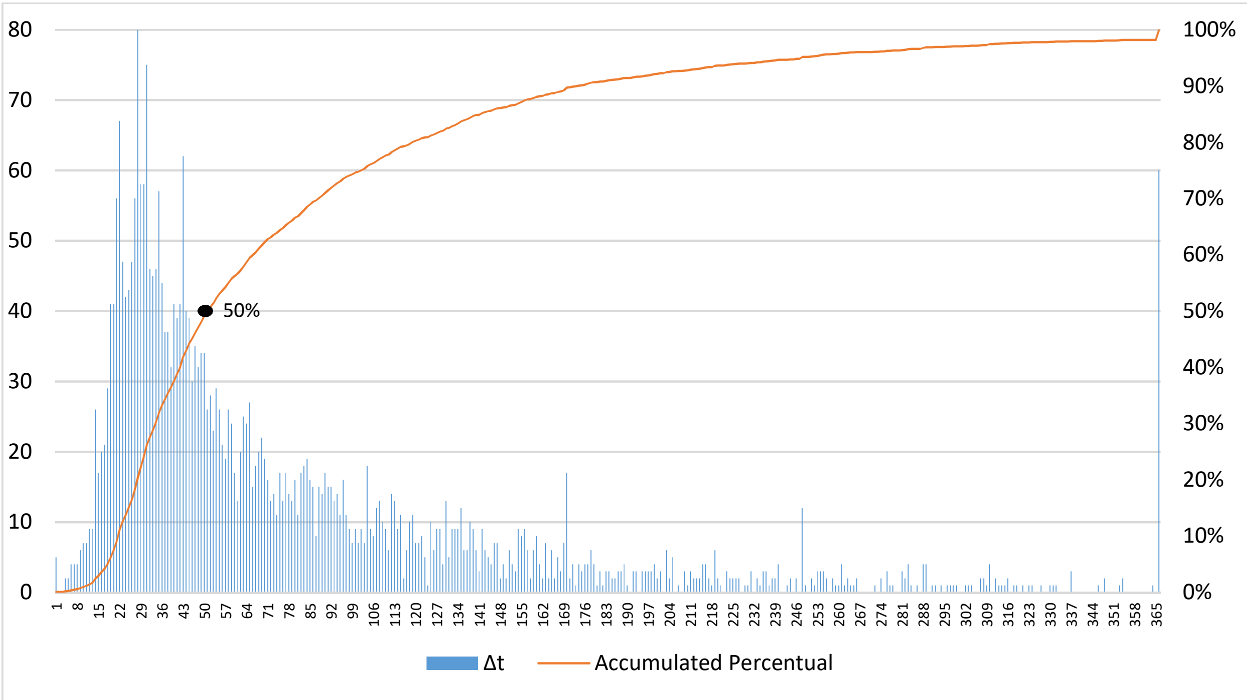

Figure 6 - Days between Production Date and Notification Date (Δt).

In the investigation phase, according to the analysis result, the status of the device is changed to “claimed”, “analysed”, “scrapped”, “blocked”, or “to return”, and the defect liability for warranty is assigned to one of three options: (1) it is determined as a responsibility of the company itself, (2) of the customer, when the defect root cause occurred only after customer delivery, i.e., due to misuse, or (3) specification, when requirements were fulfilled, and the product claimed is actually not defective.

3.2 Phase 2: Evaluation of the Complaint KPIs

3.2.1. Previous and Current KPI

The performance indicator "0 mileage" complaints used by Company A was recently changed due to the need for having an annual closing. Until 2020, the KPI adopted was the “0 mileage defective Parts per Million", abbreviated as PPM, and in 2021 it was replaced by a new indicator named "0 mileage defective Incidents per Billion", abbreviated as IPB. Both KPIs are presented in Table 2 based on eleven attributes (Neely *et al.*, 1997) to explore what constitutes a well-designed KPI. Table 2 was filled out according to the data reported in the company's information system and old reports. Most of the information was available, except the "objective" and "who acts on the data" items. That is why these fields were filled with a question mark (?) in Table 2.

Table 2 - Previous x Current KPI.

Title	0 mileage defective PPM	0 mileage defective IPB
Objective	?	?
Scope	7 out of 9 product classes	7 out of 9 product classes
Target	10 percent less than the previous year	10 percent less than the previous year
Formula	$\frac{\sum \text{Produced items in Year Y that fail}}{\sum \text{Produced quantity in Year Y}}$ For any year Y	$\frac{\sum \text{Failure notifications in Year Y}}{\sum \text{Produced quantity in Year Y}}$ For any year Y
Frequency of measurement	Updated daily	Updated daily with an annual closing
Source of data	SAP	SAP
Who measures?	Automatically	Automatically
Who acts on the data?	?	?
Notes and comments	Calculated by production date	Calculated by notification date
Frequency of review	Top-down approach	Top-down approach

Regarding the performance indicators names, while "Parts" refer to the claimed products, the word "Incident" refers to a claim notification, regardless of the amount claimed: there may be an Incident with only one part claimed, as there may be an Incident with several parts claimed. The words "Million" and "Billion" refer to the unit of measurement.

The company product portfolio includes navigation systems, instrumentation systems, and high-level car radios for the automotive industry, among other automotive electronic components. The scope of both PPM and IPB includes seven out of nine product classes. The target, defined by a top-down approach for all production facilities worldwide, requires the achievement of a result 10 percent better compared to the previous year. The source of data is an ERP system software (SAP), and all the KPI are automatically measured and displayed in a data visualization tool. The indicator reviews are done in a top-down approach (in the last revision the PPM was replaced by the IPB).

Since many product classes have an external complaint rate of around 100 incidents per million, calling it IPB (incidents per billion) may complicate the interpretation of the magnitude of the unit of measurement. In other words, it is simpler to understand the first sentence than the second:

1. 100 items were claimed for every 1 million pieces produced.
2. 100,000 items were claimed for every 1 billion pieces produced.

Another difference between the previous and the current KPI concerns the frequency of measurement. The PPM formula considers the Production Date, while the IPB considers the Notification Date. This implies that the IPB can have an absolute annual closing because when the year is over it is already known how many parts were produced and how many notifications there were, so both the numerator and the denominator of its formula are already defined. PPM, on the other hand, do not allow this annual closing at the end of the year, because only the denominator of its formula is known at this point, while the numerator can keep increasing until there are no more complaints, which can vary depending, for example, on the warranty time defined in the contracts.

Table 3 provides a hypothetical example, with made-up data for confidentiality reasons, to elucidate how the change of the KPI made it possible to carry out an annual closing for the IPB, which was the main motivation behind the KPI revision process.

Table 3 - Complaints by notification year x by production year.

		Notification Year				
		2018	2019	2020	2021	Total
Production year	2016	6	1			7
	2017	136	4	1		141
	2018	**722**	**176**	**8**		906
	2019		960	260	3	1223
	2020			939	165	1104
	2021				85	85
	Total	**864**	1141	1208	253	3466

It illustrates a situation in which among the products produced in 2018, 722 were claimed in the same year of production, another 176 products were claimed in 2019, and another 8 in 2020. Assuming that each notification (incident) refers to a unique claimed part and 12 million products were produced in 2018, the values for PPM by the end of 2018, 2019, and 2020 would be the following:

$$PPM_{2018}^{2018} = \frac{\mathbf{722}}{12000000} 10^6 = 60.17 \text{ defectives per million}$$

$$PPM_{2018}^{2019} = \frac{\mathbf{722+176}}{12000000} 10^6 = 74.83 \text{ incidents per million}$$

$$PPM_{2018}^{2020} = \frac{\mathbf{722+176+8}}{12000000} 10^6 = 75.50 \text{ incidents per million}$$

While the result for the IPB_{2018} would be already static by the end of 2018:

IPB = $\frac{\mathbf{864}}{12000000} 10^9$ = 72000 incidents per billion

It is noteworthy that the need for an annual close is what triggered Company A to change the customer complaint KPI from PPM to IPB.

3.2.2 Potential problems of the KPIs

The most important feature of a KPI is to be derived from a strategy with an explicit and clear purpose (Neely *et al.*, 1997; Neely, Gregory and Platts, 2005; Kaplan and Norton, 2007). Based on interviews with workers and managers and after consulting existing information in the company's information system page that reports on KPIs, it was apparent a lack of a clear objective, which is the main problem with both the previous and the current KPIs. Therefore, assuming certain purposes, this section presents three situations that could lead to wrong conclusions and generate misleading policy messages, which are summarized below and detailed afterward.

- Situation 1: If the objective is to control the production process, the indicators are not useful because they are lagging indicators.
- Situation 2: If the objective is to quantify the failure rate claimed to plan improvement efforts in weak areas, the current indicator is not useful. Since IPB is calculated considering the number of notifications, one single notification can contain numerous claimed parts. This leads to misinterpretation of the indicator as it hides valuable information for understanding problems.
- Situation 3: If the objective is benchmarking, the indicators are not useful. Both the previous and the current KPI aggregate product classes by giving them equal weight. This invites simplistic conclusions as some products with different complexity levels fall under the same measure and the indicator is not capable of identifying which class failed.

Situation 1:

As shown in the histogram presented in Figure 6, both failures and notifications can be out of time. This implies that the number of complaints received in a given year may not indicate the current quality because of this lagged effect. The KPI must provide timely and accurate feedback (Defeo, 2016), which in this case can be understood as the ability of the system to feed customer claims back to production facilities in the form of quality controls (Sanchez-Marquez *et al.*, 2020). However, both PPM and IPB are lagging indicators. In the manufacturing phase, if the process is changing, it is more likely that the detection of changes will be earlier through leading internal indicators than by lagging external indicators (Mitra, 2016). A lagging indicator is mostly used for review purposes in the long term, and, therefore, their focus is not to offer the opportunity for control during the production process or to measure operational performance, but to measure performance at a corporate level (Sangwa and Sangwan, 2018). The existing 8D process can trigger a prompter recalibration of internal quality control to ensure the system continues predicting, reacting, and preventing future customer complaints.

Situation 2:

A possible cause of misinterpretation of the indicator is due to its calculation by notifications (incidents) instead of by claimed parts, as this can hide valuable information for understanding problems. For example, considering that in one year (Year 3 in Figure 7) a notification is reported with several claimed products, the IPB would not show this issue, while if the indicator were calculated by PPM, this situation would be evident.

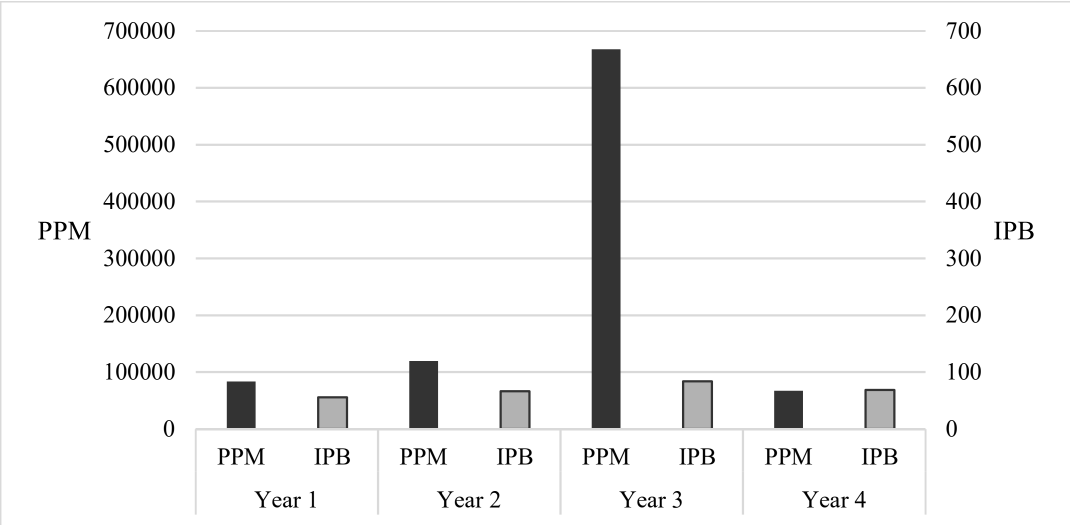

Figure 7 - PPM x IPB.

Situation 3:

The way PPM and IPB indicators are defined give equal weight to all product classes, however, they are different in their complexities. Although it is desirable that all product classes are impeccable regarding quality, they should not be treated in the same way: different strategies may be necessary to achieve the same quality level. For instance, two of the Product Classes are Chassis Sensors and Instrument Cluster, as shown in Figure 8. A Chassis Sensor is a very robust product that rarely fails and is produced in large volumes in Company A. An Instrument Cluster, on the other hand, is produced in a lesser quantity and is, comparatively, a very complex product with more critical variables to be controlled, therefore, the probability of failure is much higher. Aggregating these different Product Classes in the same indicator can generate misleading policy messages (i.e., making it looks like a company's performance is better or worse than what it is).

(**a**) (**b**)

Figure 8 - (a) Chassis Sensor; (b) Instrument Cluster

3.3 Phase 3: Suggestions for improvement

The discussion in section 3.2 presents an understanding of the definition of the previous and the current KPI, the rationale behind them, the data used, and some factors that may convey wrong messages. In this section, suggestions to overcome the reported limitations are presented.

Literature states that KPI must be derived from strategy with an explicit purpose, otherwise, they will not be understood as relevant. Thus, the first suggestion to improve the indicator is to make its purpose clear on the company's information system page that reports on KPIs. There may be several purposes for the indicator, for example: (1) Quantify complaint rate by OEMs to assess customer satisfaction; (2) Quantify complaint rate warranty decisions to assess supplier quality; (3) Quantify complaint rate according to product class to identify fault peaks, to find out the weak areas and to plan endeavours for their improvement. According to the established objective, one or more stakeholders will be responsible to act based on the data. This way, the problem of lacking “who acts on the data” field would be solved.

About the scope and the target, although a composite indicator for all the product classes may facilitate the interpretation if compared to a battery of many separate indicators, it is believed that an individual indicator with an individual target should be defined for each product class. Then, instead of aggregating all product classes with the same weight (equal to 1), it is suggested to aggregate them with different weights, considering, for example, product complexity and costs. The weighted composite indicator would better summarize the complex multi-dimensional realities to support decision-makers, by reducing the visible size of a set of indicators without dropping the underlying information base (Joint Research Centre-European Commission, 2008). For this, it is necessary to construct a weighting system and review it periodically as a part of the target and objective setting for the future.

Visualization of the results should receive proper attention, given that the visualization can influence interpretability (Joint Research Centre-European Commission, 2008). The study of KPIs and their metrics lends itself to Shneiderman's visualization mantra, "overview first, zoom and filter, then details-on-demand" (Shneiderman, 1996). Therefore, rather than just representing the indicator as a static quality figure with its target, it is important to make available visualization technique that communicates more information. Through an analytic dashboard, it is possible to enable the users to explore the indicator as they wish for emphasizing a particular set of information, for example: (1) filtering the complaints by OEMs to assess customer satisfaction; (2) filtering according to warranty decisions to assess supplier quality; (3) filtering according to product class to identify fault peaks to find out the weak areas and to plan endeavours for their improvement.

4. CONCLUSIONS

To fulfil its functions, KPIs need to be well designed, implemented, used, and reviewed. This paper analyses one of the most important KPIs used in the QMS of a company in the automotive industry, addressing the evolution of the KPI, identifying limitations, and suggesting improvements. The case study supports the relevant role of continuously reviewing existing measurement systems to keep pace with the competitive environment (Wouters and Sportel, 2005; Braz, Scavarda and Martins, 2011).

The current indicator, called IPB, was adopted in 2021. Formerly, it was calculated differently and had a different name: PPM. The main problem with both indicators is the lack of a clear purpose. Therefore, assuming certain purposes, this article presents some examples of situations that can lead to wrong conclusions and generate misleading policy messages:

- Previous (PPM) and current (IPB) KPIs are lagging indicators, not allowing to control the production process and measuring operational performance.
- IPB is calculated using the number of notifications that may contain several claimed parts. This can hide valuable information and lead to misinterpretation of data.
- In PPM and IPB, products with different levels of complexity are aggregated under the same indicator, which can invite simplistic conclusions as some products with different complexity levels fall under the same measure and the indicator is not capable of identifying which class failed.

The changes in the complaint KPI considered concepts proposed and discussed in the literature, such as the aggregation and disaggregation of measures. The disaggregation of some measures, i.e., by product classes and by customer's OEM, can improve the ability of decision makers to quickly identify the source of an operational problem and take appropriate action, in accordance with (Globerson, 1985; Joint Research Centre-European Commission, 2008). The new proposed KPI intends to more accurately identifying which product classes need more control and improvement in their production process, to consequently reduce external failures and customer complaints, driving customer satisfaction. Therefore, the suggested IPM is disaggregated by product class, and individual targets, challenging yet realistic, must be set up to each class.

Reflecting on the case study experiences, we stress that it is important at some stage to take a “fresh look” and try to think individually and in group sessions about new measures, because taking measures that already exist as a starting point for further development can inhibit change and innovation (Wouters and Sportel, 2005). Just looking at the previous indicator (PPM) and at the current indicator (IPB) hindered creativity in creating the first version of the new indicator suggested. The questions and ideas that the researchers brought up during the case study were essential to develop and revise the proposed indicator (CPPM) until reaching the final version presented here. Therefore, this study supports the statement by Wouters and Sportel (2005) that it is important to identify what exists and then to step back to have completely new ideas.

As a future research direction, it is suggested to develop a weighting system to combine the product classes into a meaningful composite indicator, involving experts and stakeholders, and to validate the proposed performance indicator by doing empirical study or case studies. Another research direction is related to test the cause-and-effect relationships between internal and external indicators, i.e., to test if the DPMO of each Product Class can be related to the complaints in order to diagnose how the quality management system works in terms of feedback, as suggested by (Sanchez-Marquez *et al.*, 2020).

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REFERENCES

Almström, P. *et al.* (2017) *Sustainable and resource efficient business performance measurement systems - The handbook*. Produktion2030.

Birch-Jensen, A. *et al.* (2020) ‘Use of customer satisfaction measurements to drive improvements’, *Total Quality Management and Business Excellence*, 31(5–6), pp. 569–582. doi: 10.1080/14783363.2018.1436404.

Bititci, U. S. *et al.* (2015) ‘Value of maturity models in performance measurement’, *International Journal of Production Research*, 53(10), pp. 3062–3085. doi: 10.1080/00207543.2014.970709.

Bititci, U. S., Cocca, P. and Ates, A. (2016) ‘Impact of visual performance management systems on the performance management practices of organisations’, *International Journal of Production Research*, 54(6), pp. 1571–1593. doi: 10.1080/00207543.2015.1005770.

Bititci, U. S., Suwignjo, P. and Carrie, A. S. (2001) ‘Strategy management through quantitative modelling of performance measurement systems’, *Int. J. Production Economics*, 69, pp. 15–22.

Blank, R. (2014) *Warranty Claims Reduction: A Modern Approach with Continuous Improvement Techniques*. CRC Press.

Braz, R. G. F., Scavarda, L. F. and Martins, R. A. (2011) 'Reviewing and improving performance measurement systems: An action research', *International Journal of Production Economics*, 133(2), pp. 751–760. doi: 10.1016/j.ijpe.2011.06.003.

Van Camp, J. and Braet, J. (2016) 'Taxonomizing performance measurement systems' failures', *International Journal of Productivity and Performance Management*, 65(5), pp. 672–693. doi: 10.1108/IJPPM-03-2015-0054.

Defeo, J. A. (2016) *Juran's Quality Handbook: The Complete Guide to Performance Excellence*. Seventh Ed. OH, United States.

Domínguez, E. *et al.* (2019) 'A taxonomy for key performance indicators management', *Computer Standards and Interfaces*, 64(December 2018), pp. 24–40. doi: 10.1016/j.csi.2018.12.001.

Globerson, S. (1985) 'Issues in developing a performance criteria system for an organization', *International Journal of Production Research*, 23(4), pp. 639–646. doi: 10.1080/00207548508904734.

Goshu, Y. Y. and Kitaw, D. (2017) 'Performance measurement and its recent challenge: a literature review', *International Journal of Business Performance Management*, 18(4), p. 381. doi: 10.1504/IJBPM.2017.087103.

Gutierrez, D. M. *et al.* (2015) 'Evolution of the performance measurement system in the Logistics Department of a broadcasting company: An action research', *International Journal of Production Economics*, 160, pp. 1–12. doi: 10.1016/j.ijpe.2014.08.012.

Hsieh, C. C. and Liu, Y. Te (2010) 'Quality investment and inspection policy in a supplier-manufacturer supply chain', *European Journal of Operational Research*, 202(3), pp. 717–729. doi: 10.1016/j.ejor.2009.06.013.

Joint Research Centre-European Commission (2008) *Handbook on Constructing Composite Indicators - Methodology and User Guide*, *OECD publishing*.

Jordan, S. and Messner, M. (2012) 'Enabling control and the problem of incomplete performance indicators', *Accounting, Organizations and Society*, 37(8), pp. 544–564. doi: 10.1016/j.aos.2012.08.002.

Kaplan, R. S. and Norton, D. P. (2007) 'Using the Balanced Scorecard as a Strategic Management System', *Harvard Business Review*, (1), pp. 1–14.

Keathley-herring, H. (2017) 'An Approach to Quantify the Factors That Affect Performance Measurement System Implementation', *Engineering Management Journal*, 29(2), pp. 63–73. doi: 10.1080/10429247.2017.1298181.

Lohman, C., Fortuin, L. and Wouters, M. (2004) 'Designing a performance measurement system: A case study', *European Journal of Operational Research*, 156(2), pp. 267–286. doi: 10.1016/S0377-2217(02)00918-9.

Lucianetti, L., Battista, V. and Koufteros, X. (2019) 'Comprehensive performance measurement systems design and organizational effectiveness', *International Journal of Operations and Production Management*, 39(2), pp. 326–356. doi: 10.1108/IJOPM-07-2017-0412.

Matos, L. dos S., Ensslin, S. R. and Ensslin, L. (2020) 'Analysis of the Life Cycles of Performance Evaluation Systems: Characteristics, Functions and Processes', *Cuadernos de contabilidad*, 21. doi: https://doi.org/10.11144/Javeriana.cc21.acvs.

Melnyk, S. A. *et al.* (2014) 'Is performance measurement and management fit for the future?', *Management Accounting Research*, 25(2), pp. 173–186. doi: 10.1016/j.mar.2013.07.007.

Mitra, A. (2016) *Fundamentals of Quality Control and Improvement*, *John Wiley*.

Neely, A. *et al.* (1996) 'Performance measurement system design: Should process based approaches be adopted?', *International Journal of Production Economics*, 46–47, pp. 423–431. doi: 10.1016/S0925-5273(96)00080-1.

Neely, A. *et al.* (1997) 'Designing performance measures: A structured approach', *International Journal of Operations and Production Management*, 17(11), pp. 1131–1152. doi: 10.1108/01443579710177888.

Neely, A. *et al.* (2000) 'Performance measurement system design: Developing and testing a process-based approach', *International Journal of Operations and Production Management*, 20(10), pp. 1119–1145. doi: 10.1108/01443570010343708.

Neely, A., Gregory, M. and Platts, K. (2005) *Performance measurement system design: A literature review and research agenda*, *International Journal of Operations and Production Management*. doi: 10.1108/01443570510633639.

Nel, J. D. and Simon, H. (2020) 'Introducing a process for radical supply chain risk management', *International Journal of Business Performance Management*, 21(1–2), pp. 149–165. doi: 10.1504/IJBPM.2020.106120.

Nudurupati, S. S., Garengo, P. and Bititci, U. S. (2021) 'Impact of the changing business environment on performance measurement and management practices', *International Journal of Production Economics*, 232(October 2020), p. 107942. doi: 10.1016/j.ijpe.2020.107942.

Riesenberger, C. A. and Sousa, S. D. (2010) 'The 8D methodology: An effective way to reduce recurrence of customer complaints?', *Lecture Notes in Engineering and Computer Science*, 2185(1), pp. 2225–2230.

S.Phabmixay, C., Rodríguez-Escudero, A. I. and Rodríguez-Pinto, J. (2019) 'Benefits from the standardisation of the complaint management system', *Total Quality Management and Business Excellence*. doi: 10.1080/14783363.2019.1633295.

Sanchez-marquez, R. *et al.* (2020) 'Diagnosis of quality management systems using data analytics – A case study in the manufacturing sector', 115. doi: 10.1016/j.compind.2019.103183.

Sanchez-Marquez, R. *et al.* (2020) 'Diagnosis of quality management systems using data analytics – A case study in the manufacturing sector', *Computers in Industry*, 115. doi: 10.1016/j.compind.2019.103183.

Sangwa, N. R. and Sangwan, K. S. (2018) 'Development of an integrated performance measurement framework for lean organizations', *Journal of Manufacturing Technology Management*, 29(1), pp. 41–84. doi: 10.1108/JMTM-06-2017-0098.

Shneiderman, B. (1996) 'The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations', in *IEEE Symposium on Visual Languages*, pp. 336–343.

Sousa, S., Nunes, E. and Lopes, I. (2015) 'On the Characterisation of Uncertainty in Performance', *Business Sustainability 2.0*, (January 2011), pp. 82–88.

Tuertmann, R. *et al.* (2016) 'Challenges and design of a data-oriented complaint and failure management', *Total Quality Management and Business Excellence*, 27(7–8), pp. 885–896. doi: 10.1080/14783363.2016.1188000.

VDA (2017) 'Quality Management in the Automotive Industry - Definition of Failure Cause Categories for 8D Reporting', pp. 1–12.

Wouters, M. and Sportel, M. (2005) 'The role of existing measures in developing and implementing performance measurement systems', *International Journal of Operations and Production Management*, 25(11), pp. 1062–1082. doi: 10.1108/01443570510626899.

Implementation and development of IPVC's equality plan in association with its management system

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STRUCTURED ABSTRACT

Purpose (Mandatory) - In the scope of the Instituto Politécnico de Viana do Castelo (IPVC) Strategic Plan 2020-2024 and its Social Responsibility strategy, was developed a project, IPVConcilia Project, aiming to invest in conditions that promote equality, inclusion, well-being, and conciliation of professional life with family and personal life its staff. The project gained a competitive funding to work on promotion of the involvement, commitment, and motivation for an active participation in the co-creation of value for an IPVC. The institution defined as a goal, to develop an increasingly sustainable and inclusive organization where people wanted and liked to work.

Design/methodology/approach (Mandatory) - IPVC developed specific training in the topic and a team to organize and implement a strategic management tool, a gender equality plan. This plan was aligned with the IPVC Code of Ethical Conduct, the Values and Management Policies and it considers the guidelines issued by the national and international bodies, the Sustainable Development Goals (SDGs) of the United Nations Agenda 2030, in particular SDG 5-Gender Equality, SDG 8-Decent Work and Economic Growth and SDG 10-Reducing Inequalities; the National Strategy for Equality and Non-Discrimination 2018-2030 Portugal + Equal (ENIND) established by the Resolution of the Council of Ministers No. 61/2018, of May 21, the Project Gender Equality in Higher Education Institutions, the GEAR program - Gender for Equality in Academia and Research of the European Institute for Gender Quality and the guidelines of the Directorate General for Research and Innovation of the European Commission and its strategic plan 2020-2024 which sets goals with a view to international competitiveness for higher education institutions, particularly at the level of equality and non-discrimination; the Guide for the Elaboration of Plans for Equality, of the ISCED (2019).

IPVC´s equality plan was developed and its processes associated with goals for organizational excellence and organizational improvement will be presented in this paper. The plan integrates strategic aims and operational objectives, actions, indicators, targets and timetable.

Findings (Mandatory) - At this moment the equality plan is being integrated in IPVC´s management system and this work will also be presented in this paper. We will present results from diagnosis and process implementation as well as future reflections on the future of Quality and Organizational Excellence based in equality and its inputs for quality management.

Social implications- The case study has clear social implications on IPVC community.

Originality/value (Mandatory)- This case study is very relevant, presenting an example of one of the first gender equality plans to be developed in higher education institutions, responding directly to the recommendations of the European Comission and Portuguese National Governmental Entities.

Keywords: Equality, Management, Diversity, Quality Management

Paper type : Case study

INTRODUTION

In the scope of the IPVC Social Responsibility strategy, concept defined by the European Commission in its Green Paper as "... the voluntary integration of social and environmental concerns by companies in their operations and in their interaction with other stakeholders." (Europeias, 2001, p. 7), the conciliation and equality in the IPVC community, was considered a priority and need to be achieved by measures of conciliation between personal and professional life and with gains in more equal opportunities. IPVC wants to ensure to all who work there the ability to maximize their potential, seeking to attract and retain talent in the institution through measures that reflect its organizational values, without leaving aside the organizational competitiveness and productivity (IPVC, 2021).

In this framework, the IPVC Presidency considered, under the IPVConcilia Project, based on the Institute's Code of Ethical Conduct (IPVC, 2020), a set of reference documents guiding the development of the Plan for Equality, of which we highlight: the Sustainable Development Goals (SDG) of the United Nations Agenda 2030, in particular SDG 5-Gender Equality, SDG 8-Decent Work and Economic Growth and SDG 10-Reducing Inequalities (United Nations, 2015, p. 14); the National Strategy for Equality and Non-Discrimination 2018-2030 Portugal + Equal (ENIND) (Presidency of the Council of Ministers, 2018), the Project Gender Equality in Higher Education Institutions (cf. https://gehei.dges.gov.pt/pt), the GEAR programme - Gender for Equality in Academia and Research of the European Institute for Gender Quality (cf. https://eige.europa.eu/gender-mainstreaming/toolkits/gear) and the guidelines of the European Commission's Directorate General for Research and Innovation (European Commission, 2021).

Gender equality is one of the main challenges facing society today, and in higher education it is complex and not easy to implement, it is an area with strong gender imbalances in all areas and at all latitudes (Robertson, et al., 2018), present also in our institution given its organisational characteristics. Although in recent years women have increased their participation at the level of the decision-making bodies of the institution and despite the high levels of training that they have reflected, there is no direct relationship between their academic qualifications and the positions they occupy in the organisational structure, similarly to the national trend seen in professions associated with economic and political decision-making (Coelho & Ferreira, 2018). It makes sense to continue to raise awareness about the need to have a equal and more balanced percentage between men and women in leadership and decision-making positions, through the implementation of transformations at the level of identities as well as in management policies (recruitment and promotion) of the institution.

In the same sense IPVC promotes the right to self-determination of gender identity and expression, recognizing that we are all equal in difference. In an attitude of doing more than saying, it seeks to guarantee the right to personal identity as an element of treatment and respect and non-discrimination of the community, in the sense identified by Guimarães in which "... we are all different and difference is an integral part of the totality." (2018, p. 1320).

The behaviors that are taught and transmitted to us from birth have undergone cultural and historical mutations, and the expectations of these behaviors are now more dissected in terms of their legal framework and consequent practice in daily relationships, with increasingly demanding consequences of non-discrimination. IPVC, due to its social responsibility towards community and also in its capacity of multinational attraction of collaborators and students, has defined a zero tolerance policy against violence in all its community, including gender violence, dating violence, domestic violence, violence in the workplace, sexual harassment, moral harassment, violence based on ethnic origin, color, nationality, ancestry and territory of origin. The objectives are not to promote leniency and condescension on the part of the community, but rather to reinforce the initiatives in the field of prevention and dissuasion that allow the eradication of stereotypes, hate speech, racial discrimination, xenophobia, and other demonstrations of intolerance that may still exist. Let us not forget that today, in contemporary society, the fight against discrimination and the promotion of equality face, new challenges that are strongly influenced by the digital age (Commission for Equality and Against Racial Discrimination (CICDR), 2020).

The issue of reconciling work and family life, a characteristic of contemporary work (Andrade, 2011, Greenhaus & Beutell, 1985), also plays a key role in the implementation of the Social Responsibility strategy, as a challenge taken on by the institution to contribute to the achievement of equality between women and men, in a shared model of care provision responsibilities, seeking to reduce income and pay gaps. The need for reconciliation is a quality issue linked to the most recent management models of large organizations, which value human capital. It is unavoidable the presence of work occupation in the family, whose management of several obligations is at the origin of conciliation conflicts, so implementing actions to promote conciliation of professional, family, and personal life, seeking to contribute to the success in these three dimensions of their lives, in a logic of mutual benefit, is one of the goals that the IPVConcilia project intends to achieve in the short term.

METODOLOGHY

The working methodology in the implementation of this purpose comprised the following phases a phase 1 in which the team developed a diagnosis, using documentary and secondary data analysis but also a collection and analysis of primary data from the IPVC. Interviews were developed with key informants. The team also applied, with adaptations, the Matrix developed by CITE to support the diagnosis CITE (2019).

In phase two we entered in the preparation of the action plan, defining the monitoring strategy and its dissemination among organizational system and among IPVC´s community. The IPV Concilia project was able to support capacity-building in gender equality, which was very helpful in all the design and awareness-raising activities of the initial start-up of the project.

Finally we aligned our Equality plan with Horizon Europe Guidance on Gender Equality Plans (GEPs) and defined our main thematic areas of intervention.

RESULTS

IPVC equality plan is now public and can be consulted here https://www.ipvc.pt/wp-content/uploads/2022/02/Plano_Igualdade_IPVC_2021_2024.pdf

Figure nº 1 – IPVC Equality plan

The main thematic areas of intervention defined were (IPVC, 2021):

1. Work-life balance and organizational culture;
2. Gender balance in leadership and decision-making;

3. Gender equality in recruitment and career progression
4. Gender mainstreaming in research and teaching content and teaching
5. Elimination of violence
6. Student Community

Also IPVC (2021) defined as Macro intervention areas the:
- Promotion and construction of gender equality and the right to self self-determination of gender identity and gender expression;
- Non-discrimination on the grounds of ethnic origin, colour, nationality ancestry, territory of origin, among others;
- Zero tolerance culture towards violence (gender violence, dating violence, domestic violence, violence in the workplace, sexual harassment, moral harassment, violence based on racial and ethnic origin, colour nationality, descent and territory of origin);
- Recognition of maternity and paternity as eminent social values eminent social values shared equally between parents - social protection in parenthood for the student/mother or the pregnant students and students who have recently given birth or are breastfeeding;
- Conciliation of professional and private life;
- Identification of needs and creation of conditions for students with special educational needs (ENEE) and employee with disabilities.

(IPVC, 2021)

The document also integrates several studies developed such as the number of teaching staff by professional category and gender; a balance of global pay gap for non-teaching staff and teaching staff; the number of staff by professional category and gender; the number of teaching staff by region and gender; number of teaching staff by age and gender; number of non-teaching staff by age and sex; number of non-teaching staff in the various modalities of working time arrangements, by gender. In the diagnosis of the Student Community in the IPVC we analysed Graduated Students in the IPVC, by gender and school; % of students enrolled in IPVC's courses.

The case also presents a diagnosis on infrastructure diagnosis and removal of architectural barriers in the institution.

The plan also presents a matrix indicators and an action plan for three years.

Figure nº2 – IPVC Matrix of actions, indicators, target and timetable

PLANO PARA A IGUALDADE IPVC 2021-2024

A. Gestão Estratégica e Institucional

Objetivo Estratégico: Promover a mudança organizacional e uma Cultura para a Igualdade.

Objetivos Operacionais: Desenvolver políticas e práticas internas de promoção da igualdade e diversidade; assumir publicamente o compromisso com a promoção da igualdade; assegurar a implementação do Plano para a Igualdade, a sua monitorização, acompanhamento e sustentabilidade; desenvolver práticas internas de gestão e estudos aplicados que organizem informação desagregada por perfis e que contribuam para uma organização inclusiva, segura e saudável.

AÇÃO	INDICADOR	META	CALENDARIZAÇÃO		
			2022	2023	2024
Constituir a Comissão para a Igualdade	Despacho emitido (2021)	-	-	-	-
	Criação de regulamento interno de funcionamento	Regulamento publicado	X		
Divulgar e dinamizar Plano para a Igualdade IPVC	Número de ações de divulgação	2 por ano	X	X	X
Realizar de ações de Capacitação nas áreas de Cidadania, Igualdade, Equidade e Diversidade	Número de ações de capacitação	1 por ano	X	X	X

This matrix integrates strategic goals, such as: to promote organizational change and a Culture for Equality and operational objectives such as: to develop internal policies and practices to promote equality and diversity; publicly commitment to the promotion of equality; ensure the implementation of the Equality Plan, its monitoring and sustainability; develop internal management practices and applied studies that organise information profiles and that contribute to an inclusive, safe and healthy organisation.

The matrix is organized in 1. Strategic and Institutional Management; 2.Science Management; 3. Culture of Elimination of Violence (Zero Tolerance); 4. Student Community; 5. Human Resource Management; 6.Occupational Health and Safety; 7.Communication and Image.

CONCLUSIONS

This case study presents an example of one of the first gender equality plans to be developed in higher education institutions, responding directly to the recommendations of the European Comission and Portuguese National Governmental Entities.

REFERENCES

Andrade, M. C. P., 2011. Work-Life balance: condições de trabalho facilitadoras da integração do papel profissional e familiar. *Exedra - Número especial*, pp. 41-53.

Coelho, L. & Ferreira, V., 2018. Segregação sexual do emprego em Portugal no último quarto de século – Agravamento ou abrandamento?. *e-cadernos CES*, Volume 29, pp. 77-98.

Comissão para a Igualdade e Contra a Discriminação Racial (CICDR), 2020. *Relatório anual 2020 - Igualdade e Não Discriminação em razão da origem Racial e Étnica, Cor, Nacionalidade, Ascendência e Território de Origem.* Lisboa: Alto Comissariado para as Migrações I.P..

European Commission, D.-G. f. R. a. I., 2021. *Horizon Europe guidance on gender equality plans.* [Online] Available at: https://data.europa.eu/doi/10.2777/876509
[Acedido em 10 junho 2022].

Europeias, C. d. C., 2001. *Livro Verde - Promover um quadro europeu para a responsabilidade social das empresas.* Bruxelas: Comissão das Comunidades Europeias.

Greenhaus, J. & Beutell, N., 1985. Sources of conclict between work and family roles. *Academy of Management Review*, pp. 76-88.

Guimarães, A. P., 2018. Discriminação em Função da Identidade de Género. Um Ultrage à Dignidade da Pessoa. *Repositório da Universidade Portucalense*, pp. 1308-1322.

IPVC, 2020. Despacho n.º 4690/2020 - Código de Conduta Ética do Instituto Politécnico de Viana do Castelo. *Diáro da República*, 17 Abril, pp. 153-162.

IPVC, 2021. *Plano para a Igualdade IPVC 2021-2024.* 1ª ed. Viana do Castelo: IPVC.

Presidência do Conselho de Ministros, 2018. Resolução do Conselho de Ministros n.º 61/2018. *Diáro da República*, 21 maio, pp. 2220-2245.

Robertson, J. et al., 2018. *EqualBITE: Gender equality in higher education.* Rotterdam: Sense Publishers.

United Nations, 2015. *Resolution adopted by the General Assembly on 25 September 2015 - Transforming our world: the 2030 Agenda for Sustainable Development.* [Online] Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E [Acedido em 10 junho 2022].

The Resonant Effect of Risks on Supply Chain Performance: A Covid-19 Perspective

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STRUCTURED ABSTRACT

Purpose - This paper investigates the resonant effect of risks on supply chain performance under COVID-19.

Design/methodology/approach - Eleven managers attended and applied the Q-sort method to evaluate the unidimensionality, reliability and validity of research concepts. Afterwards, a comparative model containing the single effects of risks on supply chain performance was developed as a basis for comparison with the theoretical model. The impacts of each risk on supply chain performance were demonstrated in both models. When the parameters of the theoretical model are greater than those in the competitive model, the resonant effect mechanism is proven and vice versa.

Findings - 63% variance of supply chain performance was explained by our risk model, which includes positive and negative resonant effects between risks. It is a remarkable rate compared with the comparative model and previous studies. Whilst a positive relationship ($\alpha \geq 0$) increases the effect of the impacted risk on the output, a negative relationship ($\alpha \leq 0$) decreases this effect, bringing benefits for companies which "see" these opportunities. Thus, practitioners should treat risk as an opportunity rather than a threat.

Research limitations/implications - A positive optimal resonant model is necessary to maximize the impact of risks on supply chain performance. Hence, companies can predict the worst-case scenario when six risks occur simultaneously. However, companies can devise mitigating techniques if a negative optimal resonant model is detected. Although risks can not be eliminated, their impact is likely to be abated by using a new paradigm.

Originality/value - The data used in this research is from a large-scale survey supported by Japanese Government to promote ASEAN sustainable socio-economic development. This dataset collected during the Covid-19 pandemic to validate our models is an interesting and topical point of this study.

Keywords: Risk management, supply chain management, supply chain risk management, supply chain performance.

Paper type: Research paper

1. Introduction

In recent years, a fairly new research method has emerged in the stream of supply chain management: Sustainable supply chain risk management (Xu et al., 2019, Song et al., 2017, Rostamzadeh et al., 2018, Moktadir et al., 2021, Cunha et al., 2019, Abdel-Basset and Mohamed, 2020, Shahin et al., 2022). This topic has aroused academia and administrators' concerns for the following rationales:

- First, supply chains are prone to disruptions by events that appear to be under control (Shahin et al., 2022). 60% of enterprises stated their supply chains were easily interrupted (Truong Quang and Hara, 2018). The reasons are: (1) supply chains have more potential for disruption; (2) they are longer and less visible, causing slow response; and (3) local "fixes" create problems in the supply chain. In contemporary society, organizations encounter over 24 sources of risks (Quang and Hara, 2019). The most common are hampered productivity (58%), customer complaints (40%), and increased work costs (39%), with losses of at least €1 billion per year due to supply chain disruptions. While sustainable supply chain can result in leaner and more efficient operations in a stable environment, it increases the fragility and vulnerability in the face of disruptions (Wagner and Bode, 2008).

  Based on anecdotal observations, risks can leave a long-lasting and detrimental impact on the supply chains. Specifically, 150 out of 350 businesses before the 1993 bombings shut down one year later. Indeed, disruptions can have adverse long-term effects on a market value and company's strategic performance measures. According to a sample of 827 interruption notices over 10 years, companies with supply chain disruptions had a 33-40% lower rate of stock returns than their industry standards within 3 years - starting one year ago and ending after disruptions 2 years (Hendricks and Singhal, 2005).

- Second, more crises and natural disasters have occurred: Flash Floods in Indonesia (January 2020), Australian Bushfires (January - March 2020), Cyclone Amphan in Bangladesh and India (May 2020), Hurricane Eta in Central America (November 2020), and especially COVID-19 pandemic. They are an omen of an increasingly unpredictable and unstable world. Furthermore, there are strong signals that such catastrophic events are enjoying a surge in frequency (Contreras et al., 2020). According to independent studies from the Epidemiology Research Center of Disaster (www.cred.be) and the world's largest insurance company Munich Re (www.munichre.com), historical data indicates that the number of natural and man-made disasters has increased substantially. In addition, Munich Re reports that the cost of disasters has increased 10 times since the 1960s.

- Third, COVID-19 has hit the global supply chains (Shahin et al., 2022), and global economy (Contreras et al., 2020). The epidemic impaired over 94% of the top 1000 companies (Fortune 2020) with estimated expenses of $4.1 trillion. The IMF has affirmed that COVID-19 would exacerbate the global economy more than the 1929 Great Recession. Global GDP growth is projected at −3.0%, much lower than the 2009 financial crisis: 0.1%.

  Lockdown and social distancing are executed as no clinical cure is available. They dealt a blow to the workforce due to travel restrictions for migrant workers. Strict measures prevent most ports from carrying containers and shock a supply-side . Moreover, this pandemic changes *consumption trends* and *behavior*.

In most situations, a single risk and multiple risks are simultaneously experienced (Wu et al., 2017). Various risks in the supply chain are interlinking, influencing the outcomes of others (Song et al., 2017; Wu et al., 2017). For instance, an earthquake may destroy a building and generate a tsunami.

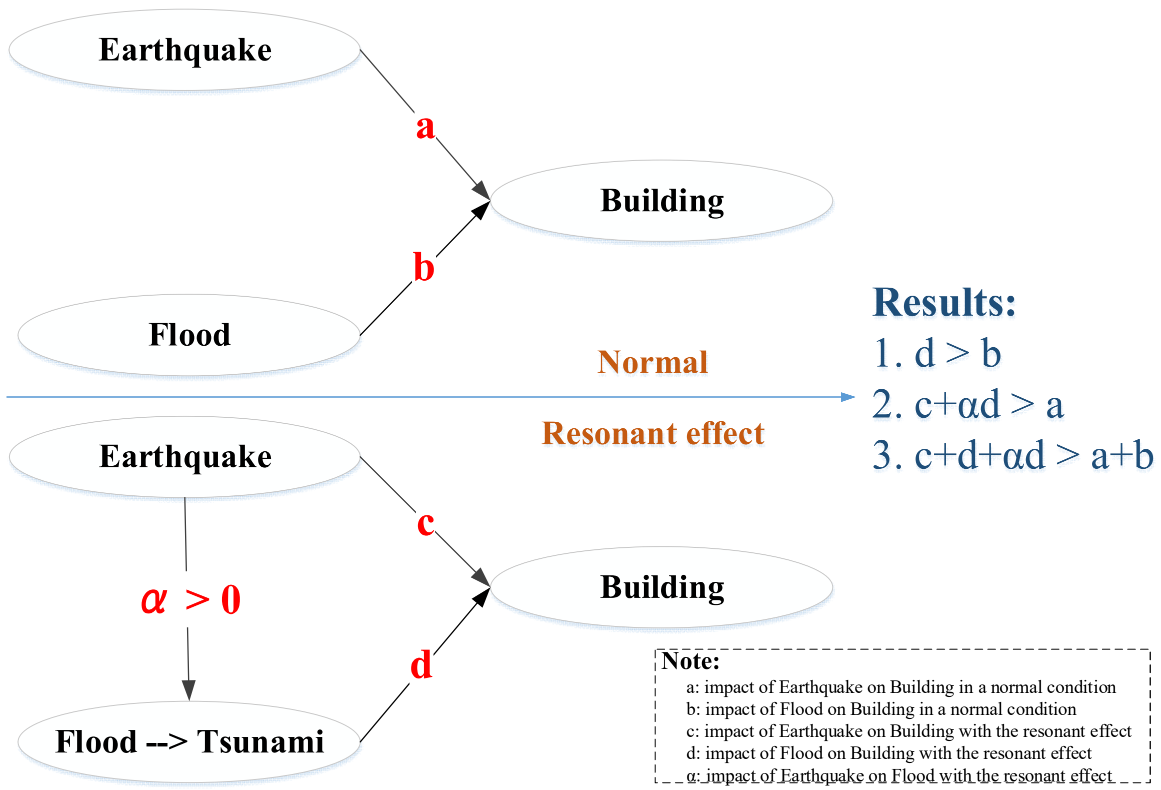

Figure 1 - Description of the resonant effect

The Tōhoku earthquake and tsunami in Miyako, Japan is an example. The displacement of the Pacific and North American plates at a rate of 8 cm/year broke the connection between two plates. Thus, the seabed collapse triggered earthquakes and the tsunami, destroying everything along the coast. It is quite likely that two risks are interdependent. The earthquake detrimentally impacts the building and the flood. Subsequently, the flood becomes a tsunami, aggravating a total loss (Figure 1). *This relationship is defined as "resonant" effect, which is still missing in literature*.

This paper, therefore, investigates the resonant effect of risks on supply chain performance under COVID-19 through two steps. Initially, the authors identify supply chain risks based on strategic management, contingency, and Risk Breakdown Structure theories to define the resonant effect. Secondly, an empirical study is conducted at the construction sector - a seriously stricken industry during COVID-19 to examine the mechanism. Findings present specific risks arising in the supply chain, their resonant effects, and the efficiency of sustainable supply chain risk management strategies.

2. Risks in the supply chain

Risk is omnipresent in the supply chain (Cunha et al., 2019). Therefore, the attitude towards risk treatment will be the decisive factor in identification and assessment. This attitude will vary across the strategy of each firm (Wagner and Bode, 2008). A classic approach of strategic management research in supply chain is to divide the concept of strategy into two aspects: process and content. Some researchers have examined the process and/or content to identify risks within organizations (Khan et al., 2008; Wagner and Bode, 2008). Additionally, as internal and external risks are essential (Quang and Hara 2019), they should be included in these models.

When the context is considered, the contingency theory assumes supply chain efficiency and excellent business results are obtained (Wagner and Bode 2008, p. 308). Supply chains must structurally fit the external influences. If this "fit" is not achieved, "opportunities are lost, costs are increased and the maintenance of the supply chain is threatened" (Truong and Hara, 2018).

The context here is defined as "the sum total of physical and social factors that cause effects on supply chain operations" (Duncan 1972, p. 314). Wagner and Bode (2008, p. 309) argue:

> *[…] Supply chain risk sources are critical contextual variables that can be internal and external to supply chains and to the acting firms in a supply chain network.*

With this argument in mind, Jüttner (2005) analysed risks in operation and supply chain. A study at 67 German automakers demonstrated a difference between internal and external risks (Thun and Hoenig 2011).

They are hierarchically and schematically depicted in a "risk circle" (Figure 2):

- One part represents external risks which are uncontrolled by a supply chain and exposed to external environment.
- The other level describes operational or static risks that align with the product flow. Supply, operational, and demand risks, known as core risks, can be better handled as they are tied to the

decisions in supply chains. These risks are common issues, which directly harm the supply chain (Truong Quang and Hara, 2018). Core risks are highly probable but have a lower impact on performance than risks outside the flow (Thun and Hoenig, 2011).

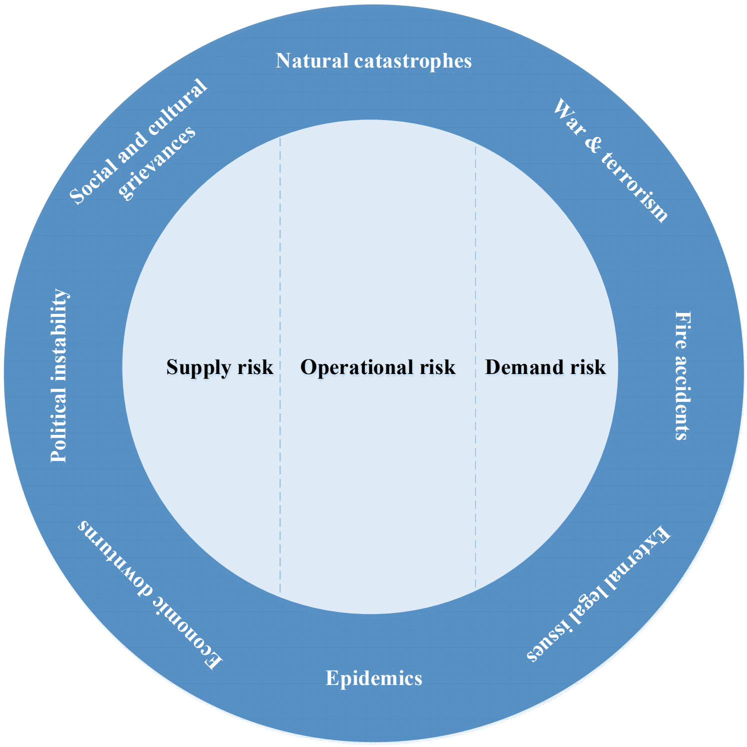

Figure 2 - Risk cycle

The next levels of risk will be determined by adopting the Risk Analysis Structure, the hierarchical and source-oriented risk group that organizes and defines the total risk exposure (Cagliano et al., 2012). This approach lays an effective foundation for a stratified classification of risks and the associated nomenclature. It serves as a framework for organizing selected risk sources and supporting risk identity. Risk Analysis Structure provides a quick list of risk areas to guide the identification of sources impacting specific activities. Each descending level represents an increasingly detailed definition of risk sources (Cagliano et al., 2012).

A systematic review of the supply chain risk management literature can develop a general risk taxonomy. The first level is internal and external. Level 2 and 3 represent the most common determinants of the supply chain (Table 1).

Table 1 - Risk Breakdown Structure frame for supply chain risk

Level 1	Level 2	Level 3	Authors
Internal	**Supply**	Supplier opportunism, dependency and responsiveness, Inability to provide competitive pricing, Supplies	(Abdel-Basset & Mohamed, 2020; Moktadir et al., 2021;

		shortage, Price fluctuations, Port capacity and strikes, Inflexibility of suppliers, Sudden default of suppliers, Inability to handle volume demand changes, Insurance issues, Inability to meet quality requirements, Transport providers' fragmentation, Damages and accidents in transportation, Custom clearance, Higher transportation costs, Storage issues, Poor design of transportation network, Improper packaging and marking details for safe transportation	Rostamzadeh et al., 2018; Truong & Hara, 2018; Wagner & Bode, 2008)
	Operations	Operator absence, Labor disputes, Employee accidents, Dissatisfaction, Lack of experience, Working conditions, Improper packaging and marking details for safe transportation, Production capacity, Quality and safety, Shorter life time products, Insufficient maintenance, Variability in process and cycle time, Improper handling/maintenance of strategic warehouses, Organization issues, Vague inspection and acceptance procedures, Frequent product recall process, Inflexibility in layout for free flow of materials, Product obsolescence	(Abdel-Basset & Mohamed, 2020; Cunha et al., 2019; Kate, 2013; Rostamzadeh et al., 2018; Song et al., 2017; Truong Quang & Hara, 2018; Nimmy et al., 2022)
	Demand	Customer dependency and fragmentation, High level service, Deficient or missing customer relation management function, Customer bankruptcy, Order fulfillment errors	(Abdel-Basset & Mohamed, 2020; George et al., 2004; Ho et al., 2015; Moktadir et al., 2021; Quang & Hara, 2019; Rostamzadeh et al., 2018; Song et al., 2017; Thun & Hoenig, 2011; Wagner & Bode, 2008; Xu et al., 2019)
External	**Human**	External legal issues, Economic and political instability, Social and cultural grievances, War & terrorism, Fire accidents	(Abdel-Basset & Mohamed, 2020; Barichello, 2020; Contreras et al., 2020; Hansen et al., 2013; Manuj & Mentzer, 2008b; Moktadir et al., 2021; Rostamzadeh et al., 2018; Song et al., 2017; Truong Quang & Hara, 2018; Wu et al., 2017; Xu et al., 2019)
	Natural	Earthquakes, Tsunami, Flood, Hurricane, Epidemics	

3. The resonant effect

Kleindorfer and Saad (2005) stated that:

> *[…] You cannot manage what you do not measure.*

Several scholars support that a good supply chain risk management strategy needs to quantify or assess the degree of danger (Lin and Zhou, 2011; Manuj and Mentzer, 2008a; Truong Quang and Hara, 2018). The majority consider the effect of each risk on different outputs (Ho et al., 2015). Normally, examining a risk will provide insights from a single perspective so the overall picture of different risks is lacking (Ho et al., 2015) when they occur simultaneously (Truong Quang and Hara, 2018; Wagner and Bode, 2008). This can hinder the undesired results, as risk mitigation and control plans focus on a single risk. Unfavourably, when many risks co-occur without the appropriate contingency plans, they will instigate devastating consequences. Moreover, a risk can spark off a domino effect (Wagner and Bode 2008). Data at 760 German-based companies, shows that information and financial risks can lead to the emergency of supply, manufacturing, and demand risks. As some strategies may adversely affect other risks, efforts should be considered (Chopra and Sodhi 2012). Klüppelberg et al. (2014) supports this view by stating that:

> *[…] We need to understand how to model and describe the dependency structure of risk. Obviously, if the risks are related in such a way that they tend to occur together and increasing the severity of the overall risk, the situation could be much more dangerous than it would otherwise.*

Returning to Tohoku, the mechanism of the resonant effect is described in figure 3. The direct damages were estimated at $14.5 billion “a + b”. This disaster damaged severely large-scale structures in north-eastern Japan. Several conventional and nuclear power plants stopped, resulting in power shortages. The damage could reach $360 billion, becoming the costliest natural disaster in history. These damages were described as “c + d + αd”.

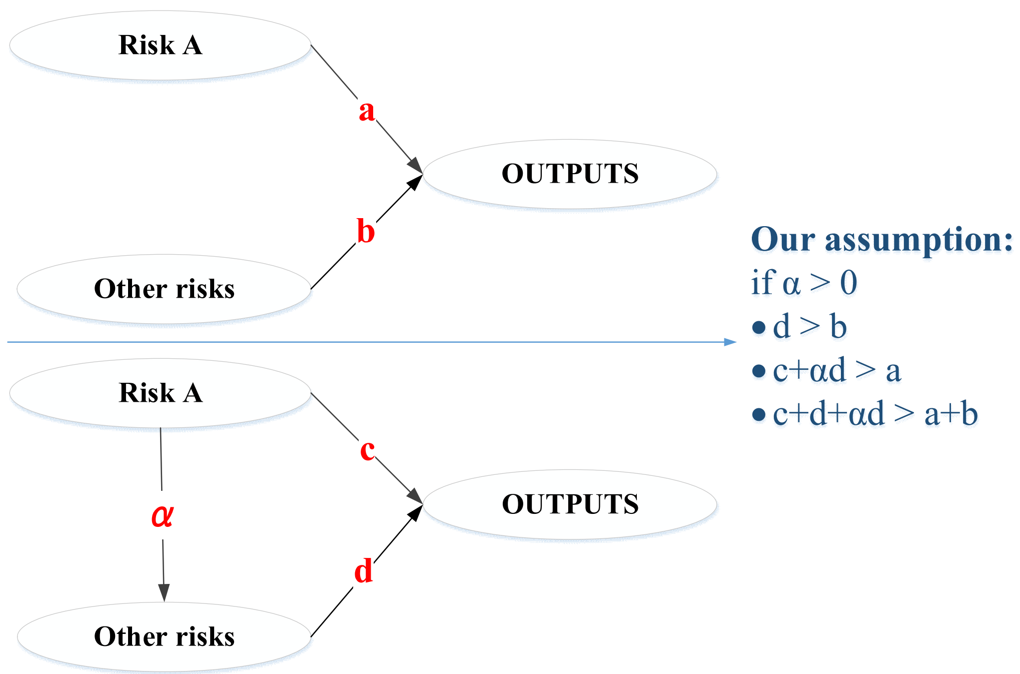

Figure 3 - The mechanism of the resonant effect

This disaster deleteriously influences the outputs and other supply chain risks - denoted as “α”. Consequently, these impacted risks become more dangerous - illustrated as “d” (>b) and through the “relationship” with these risks, the impact of the disaster will also enhance “c + αd” (>a).

"α" describes the relationship between risks. If the disaster escalates the danger of the supply chain risk, α will be greater than zero, and vice versa. There will be Beta, Gamma, Delta, and more, creating huge "resonant" effects on outputs in case various risks occur simultaneously. Therefore, we define:

Resonant effect is an increase in the degree of impact that each and all risk(s) have on outputs through the mutual interaction between the risks.

The following research hypotheses are proposed:

H. By the resonant effect, the total impacts of all risks on supply chain performance are greater than the sum of single effects.*

*H**. By the resonant effect, the impact of each risk on supply chain performance is greater than every single effect.*

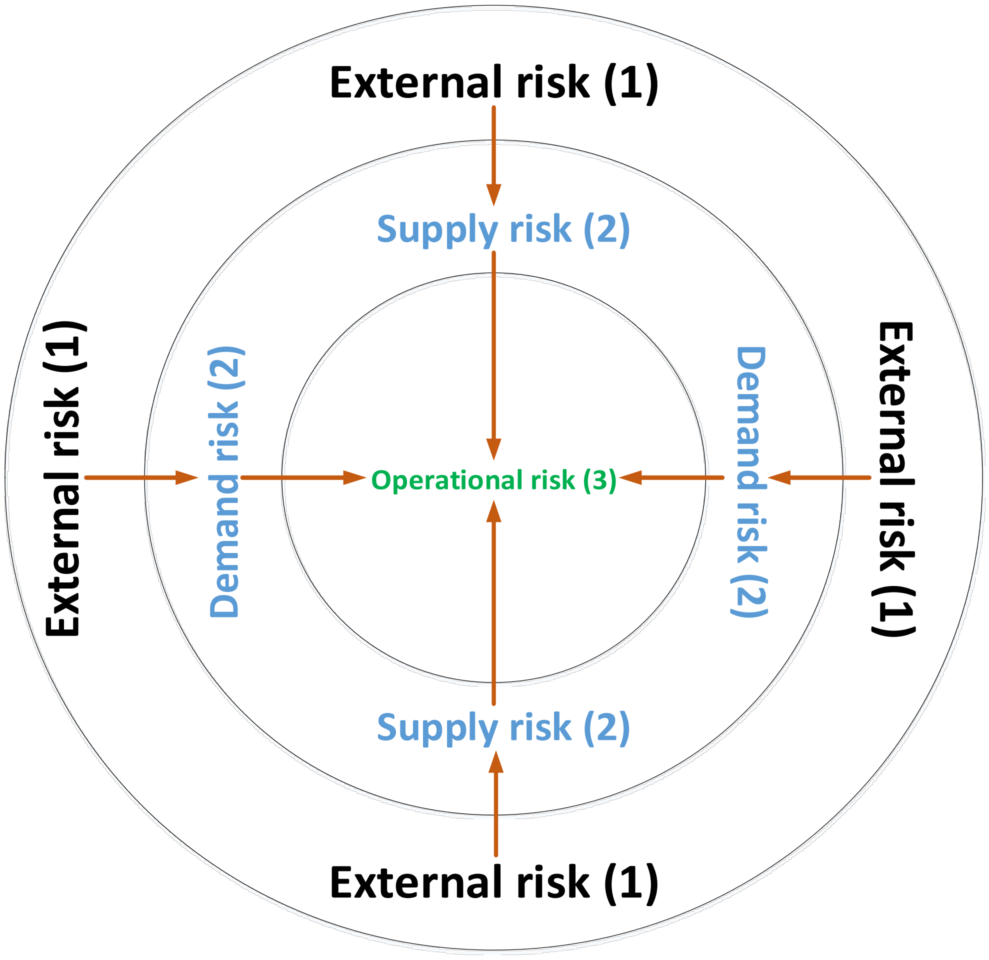

Figure 4 - The resonant effects between risks

Accordingly, these risks will be classified in a hierarchical order based on their characteristics. High-order risks will "push" the lower-order risks, which increases the severity of each and all risk(s) on supply chain performance. Risks are illustrated in Figure 4 and categorized into three main groups:

- *The first-order risks* – the "push" factors, known as external risks, e.g. Natural disaster, War & terrorism, Economic and political instability, Social and cultural grievances, Epidemics, etc. They are pernicious and rare, but they can strongly impact supply chain performance (Abdel-Basset and Mohamed, 2020; Moktadir et al., 2021; Rostamzadeh et al., 2018; Song et al., 2017; Wu et al., 2017; Xu et al., 2019).
    - In 6 minutes, the Tōhoku earthquake and tsunamis caused 19,729 deaths, 2559 missing people and $360 billion in economic damages (Fire and Disaster Management Agency, 2020).
    - The physical damage of the September 11 terrorist attack was estimated at $55 billion. The US airline industry shut down for four days. 1,000 aircraft and thousands of workers were temporarily laid off. Because of the fall in aviation demand, the Concorde commercial supersonic aircraft "empire" collapsed. To help businesses, the US Federal Reserve decreased the interest rates by half.
    - The economic downturn aggravated business operations and broke the supplier-buyer relationship (Hansen et al. 2013). Furthermore, a multitude of processes delay the transactions and capital access (Truong Quang and Hara, 2018).
    - Cultural, linguistic, and political barriers impede the supply chain (Manuj and Mentzer, 2008b). A two-year delay in the introduction of the A380 superjumbo cost Airbus €4.8 billion. Alongside technical problems, political struggles may lie at the root of this delay, since governmental pressure to 'satisfy' the interest of four European countries is different. Furthermore, cultural differences affect demand forecasting and material planning (Manuj and Mentzer, 2008b).
    - Scholars and practitioners have regarded COVID-19 as a fatal health issue (Contreras et al., 2020). Barichello (2020) finds that social distancing has damaged economic activities, especially in the service sector. Members on the downstream side of the supply chain have struggled due to demand-side shocks. With over 170 nations experiencing negative GDP per capita growth, this pandemic exerts an indirect effect on market exchange rates and monetary policy (IMF).

H1a, b, c, d: External risk adversely affects Supply risk, Demand risk, Operational risk, and Supply chain performance.

- *The second-order risks* - dynamic risks: supply and demand risks which disrupt supply chain's operations.

Supply risk

Supply risk is associated with adverse "upstream" events in supply chain network that threaten the customer's life and safety or a company's ability to meet customer demand (Wagner and Bode, 2008). Here, the company confronts risks associated with the supplier (Abdel-Basset and Mohamed, 2020; Moktadir et al., 2021; Rostamzadeh et al., 2018). These risks is an impediment to the provision of goods or services to buyers and downstream operations (Truong and Hara, 2018).

In 2000, a tire quality problem at Wilderness AT Firestone, a Ford supplier, led to 271 fatalities and over 800 injuries. The cost was estimated at $2.1 billion. Moreover, Ford Motor ended the nearly 100-year relationship with Firestone. Like Robert Bosch, in 2005, a quality adjustment of the high-pressure pump for diesel fuel injection systems occasioned considerable losses. A Bosch sub-supplier was blamed for this error, which cost millions of dollars.

Therefore, we propose the following hypotheses:

H2a, b: Supply risk adversely affects operational risk and supply chain performance.

Demand risk

Demand risk is the distribution of outcomes related to inauspicious "downstream" events in the outflow, affecting customers' purchase (Ho et al., 2015). This risk stems from the uncertainty surrounding customer requirements (Abdel-Basset and Mohamed, 2020; Moktadir et al., 2021; Rostamzadeh et al., 2018; Song et al., 2017; Thun and Hoenig, 2011; Wagner and Bode, 2008; Xu et al., 2019).

Consequently, supply chain networks are highly influenced by consumer volume and various order expectations (Quang and Hara, 2019). Moreover, when these risks arise, businesses will be incapable of forecasting market demand, leading to costly shortages, obsolescence, inefficient capacity utilization, dysfunctional operations, and poor customer service (Wagner and Bode, 2008).

George et al. (2004) argues that uncertain demand gives rise to backlogs or order shortages, planning errors and the bullwhip effect. While rapid changes in customer expectations raise costs, demand fluctuations is a hindrance to the random inventory system's performance. In 2001, Cisco Systems Inc. suffered US$2.5 billion inventories due to poor demand forecasts and rigid procurement contracts with downstream partners. Therefore, we propose the following hypotheses:

H3a, b: Demand risk adversely affects operational risk and supply chain performance.

- *The third-order risks* – the "pushed" factor: operational risk that might directly affect supply chain performance and receive resonant effects from other risks.

Operational risk refers to disruptions engendered by detrimental events such as changes in design and technology, accidents, and labour disputes, affecting supply chains in goods, services, quality, timeliness of production and profitability (Abdel-Basset and Mohamed, 2020; Cunha et al., 2019; Rostamzadeh et al., 2018;

Song et al., 2017). To minimise cost, optimal order quantities, safety stock levels, and other inventory policies must be introduced (Truong Quang and Hara, 2018).

Owing to technical issues, Mitsubishi postpones launching the new Regional Mitsubishi Aircraft for a fifth time. Experts believe that design changes could force Mitsubishi to reconsider production plans, delaying deliveries.

Strikes at two General Motors parts plants in 1998, resulting in the closure of plants, left dealerships vacant for months.

Most accidents cause employees to take three days off, worsening their ability to perform usual duties during this period (Kate 2013). While some workplace accidents are minor, HSE reports that occupational sickness or personal injury costs the UK economy an average of 27 million workdays yearly. Therefore, we propose the following hypotheses:

H4: Operational risk adversely affects supply chain performance.

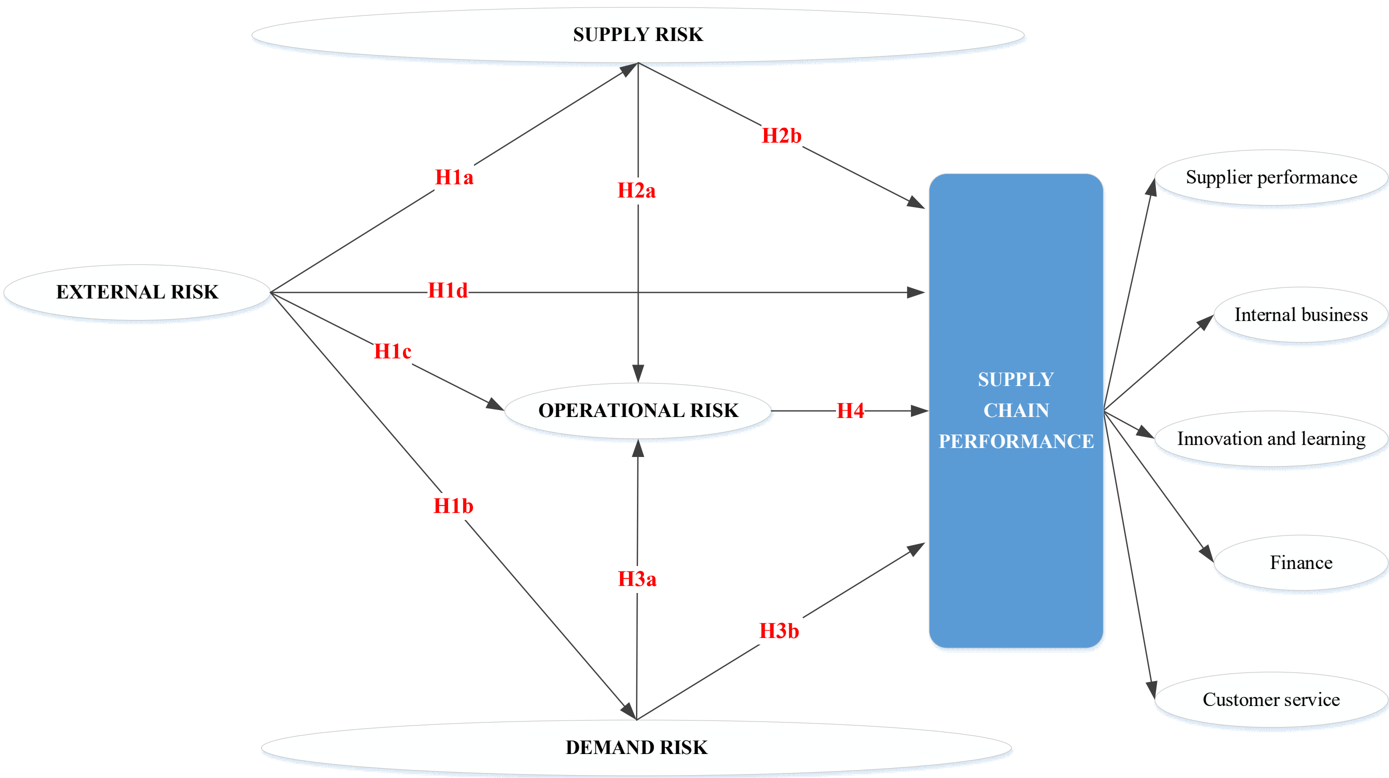

Figure 5 - Theoretical model of the risk's effect on supply chain performance

Supply chain performance

The right side of theoretical model – supply chain performance, is used to examine risk severity (Figure 5). This study identifies a series of supply chain performance measures inherited from Kaplan and Norton (1992) and Quang et al. (2016), including supplier performance, internal business, innovation and learning, customer service and finance (Appendix A).

4. Research methodology

4.1 Scale development

First, a set of scales were developed in advance. The comments from academicians were recorded and analysed. Eleven managers attended and applied the Q-sort method to evaluate the unidimensionality, reliability and validity of research concepts. Hence, the last version was established.

4.2 Data collection

The data is from a large-scale survey supported by Japanese government to promote ASEAN sustainable socio-economic development (Figure 6). The respondents are Managers from 3601 Vietnamese construction companies that have experience in supply chain management. They rated the companies' influence by risks in the past five years to evaluate their supply chain performance. Five-point Likert's scale was used with 1, representing "strongly disagree" and 5, expressing "strongly agree". The official questionnaire link was sent to these companies via email and 207 responses were received.

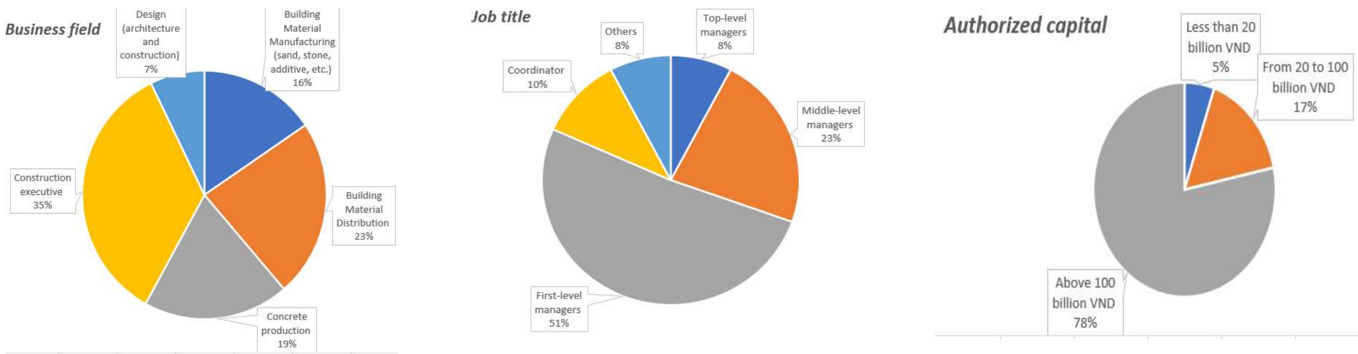

Figure 6 - Survey sample characteristics

4.3 Data analysis process

Psychometric methods are used to assess the validity and reliability of measures (Hair et al., 1995). The measures which have factor loadings greater than 0.734 meet the convergent validity criteria. All item–total correlations are above 0.483, the Cronbach's alpha coefficients range from 0.694 to 0.845, implying the reliability of the construct (Table 2).

Table 2 - Data analysis of "risk" concept

Constructs	Observed items		Supply risk	Operational risk		Demand risk	External risk		Item–total correlation
				OR1	OR2		HMR	NR	
Supply risk	Supplier bankruptcy		0.870						0.727
	Price fluctuations		0.797						0.608
	Unstable quality of inputs		0.744						0.555
	Unstable quantity of inputs		0.767						0.586
Operational risk	Design changes			0.928					0.731
	Technological changes			0.932					0.731
	Accidents				0.921				0.697
	Labour disputes				0.920				0.697
Demand risk	Demand variability					0.793			0.618
	High competition in the market					0.734			0.550
	Customer bankruptcy					0.819			0.656
	Customer fragmentation					0.832			0.669
External risk	Economic downturns						0.808		0.540
	External legal issues						0.794		0.521
	War and terrorism						0.770		0.483
	Epidemics							0.909	0.682
	Natural catastrophes							0.920	0.682
Cronbach's alpha			0.801	0.845	0.821	0.805	0.694	0.81	
Eigenvalue			2.533	1.651		2.531	1.623		
Variance extracted			63.325	86.141		63.278	71.441		

OR1 and OR2 are novel ideas derived from operational risk. While two risks relate to the operational process, they are different in terms of "who" will be responsible. OR1 and OR2, therefore, are renamed as (1) investor-related operational risks and (2) contractor-related operational risks.

External risk is split into two constructs:

- Construct 1: Human-made risks result from deliberate or negligent actions (Thun and Hoenig, 2011).
- Construct 2: Natural risks are classified into two categories: geophysical and biological (Burton, 1993).

Hence, there are some emerging additional hypotheses as described in Appendix B. The square roots of average variances extracted (AVEs) for each concept located in diagonal are greater than any correlation between it and other latent variables. The results in table 3 indicate the satisfactory discriminant validity (Fornell and Larcker, 1981).

Table 3 - Discriminant validity results

	Supply risk	Operational risk	Demand risk	External risk
Supply risk	**0.796**			
Operational risk	-0.201**	**0.928**		
Demand risk	0.181**	-0.079	**0.795**	
External risk	0.186**	-0.054	0.043	**0.845**

A comparative model containing the single effects of risks on supply chain performance was developed as a basis for comparison with the theoretical model (Figure 7).

For the 1st hypothesis – H:*

- The goodness of “fit”: This indicates an acceptable “fit” between the models and the sample data (Carmines and McIver, 1981, pp. 80). The model with higher goodness of “fit” better reflects the data.
- The coefficient of R^2 for supply chain performance: The models are estimated to demonstrate the percentage of supply chain performance.

*For the 2nd hypothesis – H**:*

- The impacts of each risk on supply chain performance in both models.

When the parameters of the theoretical model are greater than those in the competitive model, the resonant effect mechanism is proven and vice versa.

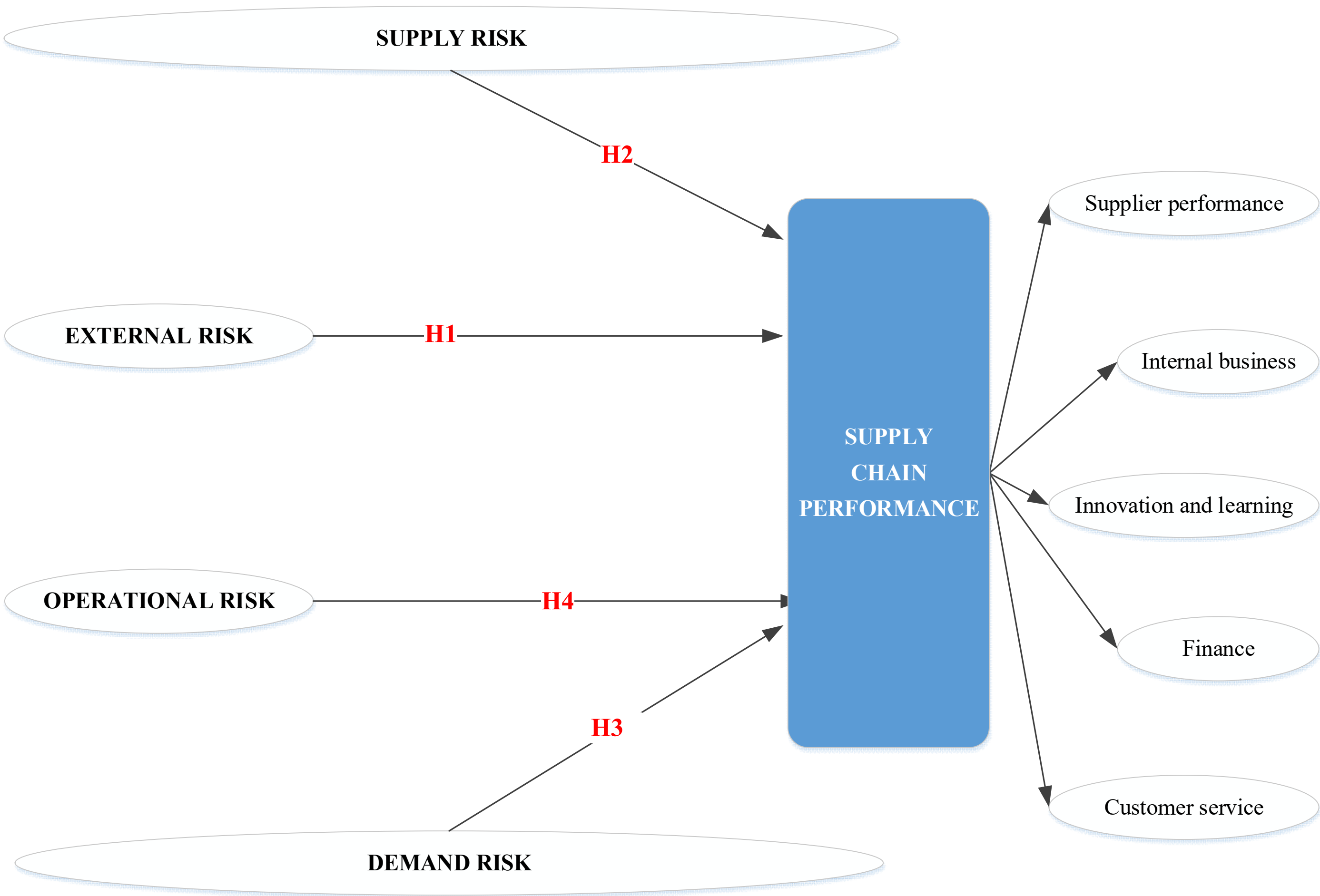

Figure 7 - Comparative model of the risk's effect on supply chain performance

5. Results

Structural Equations Modelling (SEM) results, with $\chi2/df = 1.694$, CFI = .908, Root Mean Square Error of Approximation (RMSEA) = .058, suit the data. Our resonant effect model can explain 66% variance of supply chain performance (Figure 8).

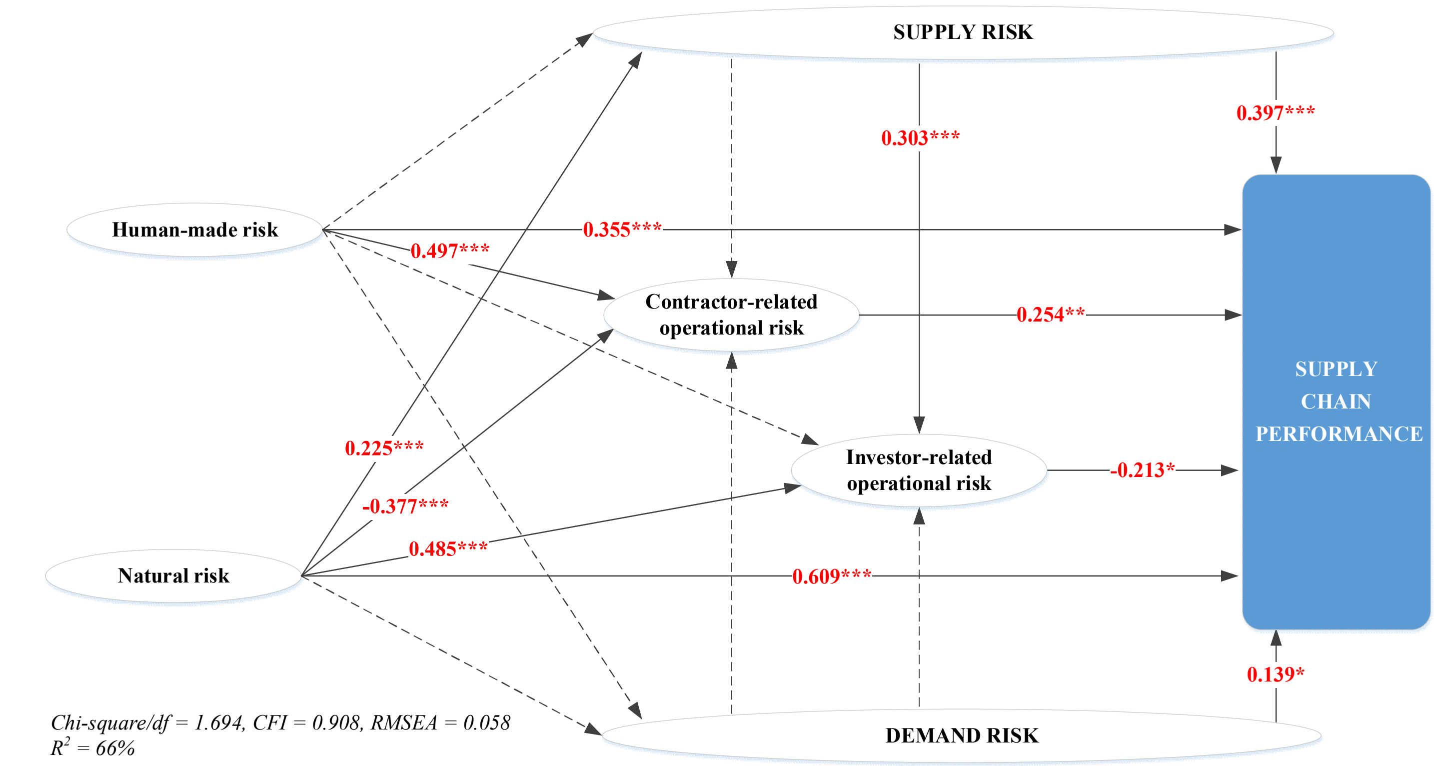

Figure 8 - SEM result

In terms of the total effect (Table 4), natural risk has the greatest impact on the supply chain (0.494). The study discovered:

- Natural risk reduces contractor-related operational risks (-0.377, Figure 8). As employees were health-conscious in the pandemic, they avoided occupational accidents. Social distancing cause organizations to downsize their operations. Thus, when the number of employees falls, that of accidents decrease.
- Investor-related operational risk, including design and technological changes, increases the efficiency of the supply chain (-0.213, Figure 8). Explaining for this strange result, some businesses were found successful by changing their designs and technologies to adapt to the current pandemic. When the lockdown policy was in effect, ports were stuck in most places in the world. The input of the supply chain was severely shocked, especially global businesses. Organizations are forced to innovate, change designs and techniques to overcome this difficult context. The design and technological changes are prompted by entities taking advantage of available resources, reducing dependence on imported raw materials. These changes lay a groudwork for new designs, technologies and processes, etc., which are suitable for the qualifications of existing workers, reducing the impact caused by the absence of foreign experts.

These intriguing findings show that risks may both damage and bring opportunities for businesses.

Table 4 - Comparison results between the SEM model and comparative model.

	SEM MODEL	DIFFERENCE

		(Standardized Total Effects)	COMPARATIVE MODEL	(RESONANT EFFECT)
RELATIONSHIPS	HMR ---> SCP	0.469	0.359	0.11
	NR ---> SCP	0.494	0.486	0.008
	SR ---> SCP	0.354	0.353	0.001
	OR1 ---> SCP	-0.217	-0.076	-0.141
	OR2 ---> SCP	0.252	0.222	0.03
	DR ---> SCP	0.113	0.102	0.011
GOODNESS OF FIT	*Chi-square/df*	1.694	2.565	
	CFI	0.908	0.776	
	RMSEA	0.058	0.087	
R^2		66.0%	56.0%	

*HMR: Human made risk; NR: Natural risk; SR: Supply risk; OR: Operational risk; DR: Demand risk; SCP: Supply chain performance

Table 4 presents comparison results between the SEM model and comparative model. The model fit of the SEM model is greater than the comparative model. In addition, the SEM model explains the higher variance of supply chain performance than the comparative model (66% and 56%, respectively), confirming our first hypothesis - Under the resonant effect, the total impacts of all risks on supply chain performance are greater than the sum of single effects.

There are not remarkable differences in the impact of contractor-related operational, supply and natural risk on supply chain performance between two models. This does not mean that the resonance effect is not supported by the survey data. In contrast, as mentioned, the resonant effect exists when there is the relationship between two risks. Accordingly, a positive relationship ($\alpha \geq 0$) will increase the effect of the impacted risk on the output whereas a negative relationship ($\alpha \leq 0$) will decrease this effect. For instance,

- Human-made risk increases the severity of contractor-related operational risk (0.497), while natural risk reduces the danger level of this risk (-0.377), resulting in a negligible increase in the impact of contractor-related operational risk on supply chain performance compared to the comparative model (Figure 8).
- Due to the harmful impact of natural risk on contractor-related operational risk, the total effect of natural risk on supply chain performance diminishes.
- Supply risk is significantly increased by natural risk (0.225). However, as investor-related operational risk has a negative impact on supply chain performance (-0.213), the indirect impact of supply risk on supply chain performance is a negative number, resulting in a decrease of the total effect of supply risk on supply chain performance.

Regarding demand risk, there is no significant relationship identified between it and other risks, so its impact on supply chain performance in the resonant model will be quite similar to the comparative model.

Investor-related operational risk is considerably increased by natural and supply risk, however, it has a destructive impact on supply chain performance. Thus, its resonant effect on supply chain performance is negative (-0.141).

The positive resonant effect is prominent in human-made risk as it accelerates the danger of contractor-related operational risk (0.497) and the consequence is a greater effect on supply chain performance (0.11).

The above discussion has reinforced the mechanism of the resonant effect in this study, even though the second hypothesis is not completely satisfied.

6. Discussion and final remarks

This research broadens the understanding of relationship between risks and supply chain performance to examine, define and develop the resonance effect. A new approach in supply chain risk management literature investigates all risks in an interactive system that might influence outputs. A 63% variance of supply chain performance explained by the resonance effect risk model is a noteworthy rate as supply chain performance is not only influenced by risks, but also by other factors, such as supply chain practices and strategies. Therefore, companies may reduce the impact of risks by controlling the resonant effect mechanism.

With the same approach, 760 German-based companies' resultant model explained 6% variance (Wagner and Bode 2008). Therefore, each impact is relatively small (Table 5).

This may be explained in several ways. Conducting the survey during COVID-19 is one factor which promotes the supply chain risks and affects the perception of risk. There was misinformation that customers increased stocks, shocked supply, and screwed up plans. Disorders reduce business efficiency and order fulfilment (Trautrims et al., 2020). Thus, government should form official channels to reduce distorted information and introduce support policies to help businesses.

Table 5 - Comparison between our findings and Wagner and Bode (2008)

	Relationships			Our findings (Standardized Total Effects)	Wagner & Bode (2008)
External risk	HMR	--->	SCP	0.469	-0.03
	NR	--->	SCP	0.494	0.01
Internal risk	SR	--->	SCP	0.354	0.09
	OR1	--->	SCP	-0.217	
	OR2	--->	SCP	0.252	NA
	DR	--->	SCP	0.113	0.08
R^2				66%	6%

The notion to reduce the resonant effect will minimize the coefficient of "α". As a corollary, the theoretical model can be "a map" to achieve this purpose. Initially, efforts should start with operational risks as they receive resonant effects from other risks. Noted that investor-related operational risk enhances supply chain performance, practitioners should perceive it as an opportunity. The attention should be on supply and demand risk, pushing operational risk and being pushed by natural and human-made risk. "Push" factors are mitigated in the last step. Other risks are controlled, reducing the intensity of external risks.

An interesting finding is that natural risk reduces the danger of contractor-related operational risks. However, this interaction alleviates the impact of risk, bringing benefits for companies.

To address key contingency risks, managers should weigh cost and benefits trade-offs. Some sustainable supply chain management strategies are put forward:

- During COVID-19, companies avoid shortages by impact consideration, reusability, and recycling of materials. Futurecraft Loop Adidas has created a running shoe from 100% recyclable materials. Ultimately, supply chain sustainability has a monetary value.
- Local sourcing reduces the dependence on supply, thereby bringing flexibility and reducing costs. Local companies hold a tight and fast-paced supply chain, which retains consumers and attracts new ones.
- Technology reduces material requirements. 3D printing saves resources by layering materials, and the plastic waste is recyclable. Furthermore, as 3D printing uses grids, base materials can be reduced by 50%.
- Design and technological changes provide advantages, boosting the sustainability. Even after the end of Jaguar's lifespan is reached, cars are 85% recyclable and 95% recoverable, with no more than 5% going to landfill.
- Innovative designs and technologies cut energy usage and boost employee flexibility. The real-time tracking system enables MAERSK to minimize delays, increase capacity, and optimize the speed of ships to achieve 43% drop in emissions per container.

Most supply chain risk management research is qualitative (Vural, 2017). Large-scale empirical studies are few and mostly descriptive (Vural, 2017). Therefore, using: (1) knowledge-based (assessment by experts via Q-sort method) and (2) data-driven (empirical data in construction sector) to identify and assess supply chain risks, is a novel approach in literature. The findings of this research must be validated across nations. Thus, an international survey provides intriguing insights into risk management.

One limitation of this study is that the SEM model only confirms the mechanism of the resonant effect based on the proposed hypotheses about the relationship between concepts, without optimal "resonant" models.

A positive optimal resonant model maximizes the impact of risks on supply chain performance. Hence, companies can predict the worst-case scenario, as six risks occur simultaneously. However, companies can devise mitigating techniques if a negative optimal resonant model is detected. Although we cannot eliminate risks, we can reduce their impact (Rao Tummala and Leung, 1996) - that is when a new paradigm is needed.

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References

Abdel-Basset, M., Mohamed, R., 2020. A novel plithogenic TOPSIS-CRITIC model for sustainable supply chain risk management. Journal of Cleaner Production. 247, 119586.

Barichello, R., 2020. The COVID-19 pandemic: Anticipating its effects on Canada's agricultural trade. Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie. 68(2), 219-224.

Burton, I., 1993. The environment as hazard. Guilford press.

Cagliano, A.C., De Marco, A., Grimaldi, S., Rafele, C., 2012. An integrated approach to supply chain risk analysis. Journal of risk research. 15(7), 817-840.

Chopra, S., Sodhi, M., 2012. Managing risk to avoid supply-chain breakdown. MIT Sloan Management Review (Fall 2004). 46(1), 53-61.

Contreras, L.E.V., Perkins, K.M., Ellenbecker, M., Moure-Eraso, R., Vega, N.E.M., 2020. COVID-19 pandemic lessons to facilitate future engagement in the global climate crisis. Journal of Cleaner Production. 125178.

Cunha, L., Ceryno, P., Leiras, A., 2019. Social supply chain risk management: A taxonomy, a framework and a research agenda. Journal of Cleaner Production. 220, 1101-1110.

Duncan, R.B., 1972. Characteristics of organizational environments and perceived environmental uncertainty. Administrative science quarterly. 17(3), 313-327.

Fornell, C., Larcker, D.F., 1981. Evaluating structural equation models with unobservable variables and measurement error. Journal of marketing research. 39-50.

George, A.Z., Lisa, M.E., Joseph, R.C., Joseph, L.C., 2004. An analysis of supply risk assessment techniquesnull. International Journal of Physical Distribution & Logistics Management. 34(5), 397-413.

Hair, J.F., Anderson, R.E., Tatham, R.L., Black, W.C., 1995. Multivariate data analysis with readings, 4th ed. New Jersy, Prentice Hall.

Hansen, E., Nybakk, E., Panwar, R., 2013. Firm performance, business environment, and outlook for social and environmental responsibility during the economic downturn: findings and implications from the forest sector. Canadian Journal of Forest Research. 43(12), 1137-1144.

Hendricks, K.B., Singhal, V.R., 2005. An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. Production and Operations management. 14(1), 35-52.

Ho, W., Zheng, T., Yildiz, H., Talluri, S., 2015. Supply chain risk management: a literature review. International Journal of Production Research. 53(16), 5031-5069.

Jüttner, U., 2005. Supply chain risk management: Understanding the business requirements from a practitioner perspective. The International Journal of Logistics Management. 16(1), 120-141.

Kaplan, R.S., Norton, D., 1992. The Balanced Scorecard: Measures that Drive Performance. Harvard Business Review. 70(1), 71–79.

Kate, S., 2013. Health and Safety Executive - Annual Statistics Report for Great Britain 2012/13. http://www.hse.gov.uk/statistics/overall/hssh1213.pdf. (Accessed 07 June 2016.

Khan, O., Christopher, M., Burnes, B., 2008. The impact of product design on supply chain risk: a case study. International Journal of Physical Distribution & Logistics Management. 38(5), 412-432.

Kleindorfer, P.R., Saad, G.H., 2005. Managing disruption risks in supply chains. Production and operations management. 14(1), 53-68.

Klüppelberg, C., Straub, D., Welpe, I.M., 2014. Risk-A Multidisciplinary Introduction. Springer.

Lin, Y., Zhou, L., 2011. The impacts of product design changes on supply chain risk: a case study. International Journal of Physical Distribution & Logistics Management.

Manuj, I., Mentzer, J.T., 2008a. Global supply chain risk management strategies. International Journal of Physical Distribution & Logistics Management.

Manuj, I., Mentzer, J.T., 2008b. Global supply chain risk management strategies. International Journal of Physical Distribution & Logistics Management. 38(3), 192-223.

Moktadir, M.A., Dwivedi, A., Khan, N.S., Paul, S.K., Khan, S.A., Ahmed, S., Sultana, R., 2021. Analysis of risk factors in sustainable supply chain management in an emerging economy of leather industry. Journal of Cleaner Production. 283, 124641.

Nimmy, S. F., Hussain, O. K., Chakrabortty, R. K., Hussain, F. K. & Saberi, M. 2022. Explainability in supply chain operational risk management: A systematic literature review. Knowledge-Based Systems*,* 235**,** 107587.

Quang, H.T., Hara, Y., 2019. The push effect of risks on supply chain performance: service-oriented firms. Business Process Management Journal. 25(7), 1734-1758.

Quang, H.T., Sampaio, P., Carvalho, M.S., Fernandes, A.C., An, D.T.B., Vilhenac, E., 2016. An extensive structural model of supply chain quality management and firm performance. International Journal of Quality & Reliability Management. 33(4), 444-464.

Rao Tummala, V., Leung, Y., 1996. A risk management model to assess safety and reliability risks. International Journal of Quality & Reliability Management. 13(8), 53-62.

Rostamzadeh, R., Ghorabaee, M.K., Govindan, K., Esmaeili, A., Nobar, H.B.K., 2018. Evaluation of sustainable supply chain risk management using an integrated fuzzy TOPSIS-CRITIC approach. Journal of Cleaner Production. 175, 651-669.

Shahin, A., Balouei Jamkhaneh, H. & Shahin, R. 2022. Supply Chain Risk Management under Covid-19: A Review and Research Agenda. Developments in Information & Knowledge Management for Business Applications**,** 561-580.

Song, W., Ming, X., Liu, H.-C., 2017. Identifying critical risk factors of sustainable supply chain management: A rough strength-relation analysis method. Journal of Cleaner Production. 143, 100-115.

Thun, J.-H., Hoenig, D., 2011. An empirical analysis of supply chain risk management in the German automotive industry. International journal of production economics. 131(1), 242-249.

Trautrims, A., Schleper, M.C., Cakir, M.S., Gold, S., 2020. Survival at the expense of the weakest? Managing modern slavery risks in supply chains during COVID-19. Journal of Risk Research. 23(7-8), 1067-1072.

Truong, H.Q., Hara, Y., 2018. Supply chain risk management: manufacturing-and service-oriented firms. Journal of Manufacturing Technology Management. 29(2), 218-239.

Truong Quang, H., Hara, Y., 2018. Risks and performance in supply chain: the push effect. International Journal of Production Research. 56(4), 1369-1388.

Vural, C.A., 2017. Service-dominant logic and supply chain management: a systematic literature review. Journal of Business & Industrial Marketing.

Wagner, S.M., Bode, C., 2008. An empirical examination of supply chain performance along several dimensions of risk. Journal of business logistics. 29(1), 307-325.

Wu, K.-J., Liao, C.-J., Tseng, M.-L., Lim, M.K., Hu, J., Tan, K., 2017. Toward sustainability: using big data to explore the decisive attributes of supply chain risks and uncertainties. Journal of Cleaner Production. 142, 663-676.

Xu, M., Cui, Y., Hu, M., Xu, X., Zhang, Z., Liang, S., Qu, S., 2019. Supply chain sustainability risk and assessment. Journal of Cleaner Production. 225, 857-867.

Appendix

A. Data analysis of "supply chain performance" concept

	Observed items	**1**	**2**	**3**	**4**	**Item – total correlation**
Supplier performance	Reliability				.891	0.623
	Response time				.700	0.623
Internal business	Amount of production waste		0.517			0.551
	Costs of inventory management		0.765			0.635
	Workforce productivity		0.806			0.58
Innovation and learning	Number of new product developed per year			0.778		0.635
	Workforce flexibility			0.871		0.635
Customer service	Delivery timeliness	Deleted				
	Percentage of "perfect orders" delivered	Deleted				
	Product value perceived by the customer	0.658				0.552
	Product/ Service quality	0.939				0.673
	Response time to customer queries	0.473				0.481
Finance	Market share growth	Deleted				
	Return on Investments (ROI)	Deleted				
Cronbach's alpha		0.738	0.757	0.746	0.767	
Eigenvalue		1.131				
Variance extracted		74.661				

Appendix A. Data analysis of "supply chain performance" concept

B. Hypotheses testing results

Hypotheses	Statements			Standardized Regression Weights
H1.1a	Human-made risk	-->	Supply risk	Unsupported
H1.1b	Human-made risk	-->	Demand risk	Unsupported
H1.1c1	Human-made risk	-->	Investor-related operational risk	0.497***
H1.1c2	Human-made risk	-->	Contractor-related operational risk	Unsupported
H1.1d	Human-made risk	-->	Supply chain performance	0.355***
H1.2a	Natural risk	-->	Supply risk	0.225***
H1.2b	Natural risk	-->	Demand risk	Unsupported
H1.2c1	Natural risk	-->	Investor-related operational risk	-0.377***
H1.2c2	Natural risk	-->	Contractor-related operational risk	0.485***
H1.2d	Natural risk	-->	Supply chain performance	0.609***
H2a1	Supply risk	-->	Investor-related operational risk	Unsupported
H2a2	Supply risk	-->	Contractor-related operational risk	0.303***
H2b	Supply risk	-->	Supply chain performance	0.397***
H3a1	Demand risk	-->	Investor-related operational risk	Unsupported
H3a2	Demand risk	-->	Contractor-related operational risk	Unsupported
H3b	Demand risk	-->	Supply chain performance	0.139*
H4a	Investor-related operational risk	-->	Supply chain performance	0.254**

H4b	Contractor-related operational risk	-->	Supply chain performance	-0.213*

Appendix B. Hypotheses testing results

C. The SEM mathematic models

Measurement model: is the same between the theoretical model and the comparative model.

$$\begin{pmatrix} HMR_1 \\ HMR_2 \\ HMR_3 \\ NR_4 \\ NR_5 \\ SR_6 \\ SR_7 \\ SR_8 \\ SR_9 \\ DR_{10} \\ DR_{11} \\ DR_{12} \\ DR_{13} \\ OR_{14} \\ OR_{15} \\ OR_{16} \\ OR_{17} \\ SP_{18} \\ SP_{19} \\ IB_{20} \\ IB_{21} \\ IB_{22} \\ IL_{23} \\ IL_{24} \\ CS_{25} \\ CS_{26} \\ CS_{27} \\ SP \\ IB \\ IL \\ CS \end{pmatrix} = \begin{pmatrix} a_1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ a_3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_4 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & a_5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & a_9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{10} & 0 & 00 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & a_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{14} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & a_{15} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{16} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & a_{17} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{18} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & a_{19} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{20} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{21} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{22} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{23} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{24} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{25} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{26} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{27} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{28} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{29} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{30} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & a_{31} \end{pmatrix} \begin{pmatrix} HMR \\ NR \\ SR \\ DR \\ OR1 \\ OR2 \\ SP \\ IB \\ IL \\ CS \\ SCP \end{pmatrix} + \begin{pmatrix} e_1 \\ e_2 \\ e_3 \\ e_4 \\ e_5 \\ e_6 \\ e_7 \\ e_8 \\ e_9 \\ e_{10} \\ e_{11} \\ e_{12} \\ e_{13} \\ e_{14} \\ e_{15} \\ e_{16} \\ e_{17} \\ e_{18} \\ e_{19} \\ e_{20} \\ e_{21} \\ e_{22} \\ e_{23} \\ e_{24} \\ e_{25} \\ e_{26} \\ e_{27} \\ e_{28} \\ e_{29} \\ e_{30} \\ e_{31} \end{pmatrix} \tag{C.1}$$

Structural model

- The theoretical model

$$\begin{pmatrix} SR \\ DR \\ OR1 \\ OR2 \\ SCP \end{pmatrix} = \begin{pmatrix} \alpha_1 & \alpha_2 & 0 & 0 & 0 & 0 \\ \alpha_1 & \alpha_2 & 0 & 0 & 0 & 0 \\ \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & 0 & 0 \\ \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & 0 & 0 \\ \alpha_1 & \alpha_2 & \alpha_3 & \alpha_4 & \alpha_5 & \alpha_6 \end{pmatrix} \begin{pmatrix} HMR \\ NR \\ SR \\ DR \\ OR1 \\ OR2 \end{pmatrix} + \begin{pmatrix} d_1 \\ d_2 \\ d_3 \\ d_4 \\ d_5 \end{pmatrix} \tag{C.2}$$

- The comparative model

$$(SCP) = (\beta_1 \quad \beta_2 \quad \beta_3 \quad \beta_4 \quad \beta_5 \quad \beta_6) \begin{pmatrix} HMR \\ NR \\ SR \\ DR \\ OR1 \\ OR2 \end{pmatrix} + (r_1) \tag{C.3}$$

where a_{ij} / α_{ij} / β_j are coefficients, e_i / d_i / r_i are errors and disturbance.

Application of artificial intelligence methods for educational organizations' quality management systems (QMS) effectiveness improvement

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ABSTRACT

Purpose - Distance learning mandates and other limitations imposed due to the COVID-19 outbreak have incentivized technological transformations of the higher education system. The ongoing changes caused by the pandemic underpin several significant tendencies, such as mass customization of education, decentralization and higher flexibility of the education system, the multi-aspect result analysis throughout the educational process, etc.

One of the principal aspects of present-day higher education is its integration into the stakeholding context, with education system stakeholders not engaged directly in goal-setting, control, and estimation activities. In other words, the social environment around higher education is expanding, especially given its current state of diversification. This paper aims to analyze the current status of quality management systems applied by educational institutions during the pandemic and the post-pandemic period, their further development, and ways to increase their efficiency via artificial intelligence methods.

Design/methodology/approach – The analysis involved monitoring the functioning of QMS-applying educational systems and studying the public data on higher and secondary education institutions and their activities in several countries before, during, and after the COVID-19 pandemic. The data are provided by the International Organization for Standardization, with the sample comprising over 2,347,791 facilities (the number of sites aggregated from "ISO Survey of certifications to management system standards - Full results 2020"). The purpose of the analysis was to find tendencies related to educational institutions. This study also includes the results of observation of AI implementation by educational institutions and provides insights based on the authors' personal experience of applying those practices. One of the universities participating in the research provided the enrollment campaign results for AI method validation; the sample consists of

20,284 enrollment records. This sample was used to validate the algorithm developed within the framework of this study.

Findings – The study demonstrates that the COVID-19 pandemic had a significant global-scale impact on the functioning of educational organizations, creating a window of opportunity for the systemic introduction of AI methods to administrative, scientific, educational, auxiliary, and other processes.

Originality/value – The authors analyze the opportunities for managing educational organizations, specifically higher education institutions, from the QMS standpoint. This paper provides a promising approach to systematizing AI methods applied to educational management.

Keywords: Quality management systems, ISO 9001, artificial intelligence, educational organizations.

Paper type: Research paper

INTRODUCTION

Multiple studies have focused on ways that could improve the quality of education (Shanaida, Vitenko, Droździel, Madleňák 2019). ISO 9000 standards and their publication in 1987 became a milestone for educational organizations and their development (Doherty, 1995). At that time, standards for quality management systems were mainly targeting industrial operations. Yet with every new version of the flagship ISO 9001 standard family (1994, 2000, 2008, and 2015), QMS standards were becoming more and more universal in their scope and could demonstrate effective results when implemented by educational organizations (Stimson, 2003; Thonhauser, Passmore, 2006; Celik, Ölcer, 2018).

The first international standard providing requirements for educational processes, ISO 29990, "Learning services for non-formal education and training — Basic requirements for service providers," was issued in 2010. It was replaced in 2018 by another international standard that provisioned specific requirements for management systems implemented by educational organizations, based on the High-Level Structure (HLS) - ISO 21001 "Educational organizations — Management systems for educational organizations — Requirements with guidance for use." The academic community's reaction was ambiguous (Guerra, Ramos, Roque 2020; Silaeva and Semenov 2018). It is worth noting that the standard is currently being revised, with a new version planned for release in 2023.

Nevertheless, quality management systems have become an essential tool that facilitates the constant improvement of educational organizations, with ISO 9001 being the unquestionable leader in applying standardized QMS to educational activities. It laid the groundwork for other management system standards and their introduction to educational institutions. According to the “ISO Survey of certifications to management system standards - Full results 2020”, educational organizations are certified for their compliance with several international standards, including ISO 9001, ISO 14001, ISO/IEC 27001, ISO 45001, ISO 50001, ISO 22301, ISO/IEC 20000-1, ISO 28000, ISO 37001, and ISO 39001. The report provides statistically significant data for those standards, divided into three major groups due to varying statistical evidence (Fig. 1-3).

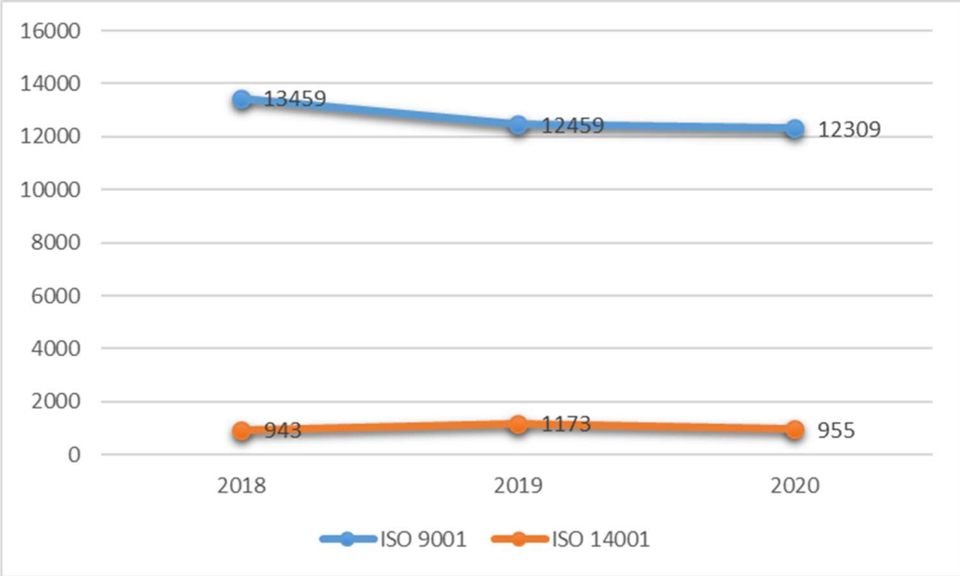

Figure 1 – The number of certificates awarded to educational organizations worldwide in 2018-2020 (within 900-14000 range), according to the “ISO Survey of certifications to management system standards - Full results 2018, 2019, 2020”.

The first group comprises the most popular standards, including ISO 9001, one of the main objects of our study, and ISO 14001, the latter demonstrating stagnation in recent years. Both have been in use for a long time, so we are probably dealing with a case of market saturation.

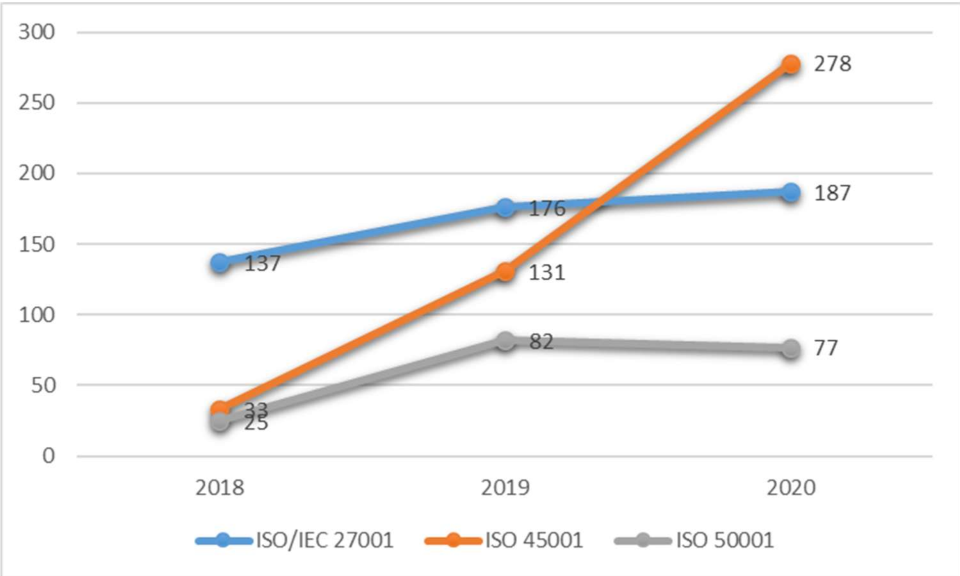

Figure 2 – The number of certificates awarded to educational organizations worldwide in 2018-2020 (within the 20-300 range), according to the "ISO Survey of certifications to management system standards - Full results 2018, 2019, 2020".

The second group encompasses standards for educational organizations that are relatively new to the market, e.g., ISO/IEC 27001, ISO 45001, and ISO 50001. While the first two standards demonstrate continuous growth, albeit different in intensity, the third standard stopped expanding in 2019.

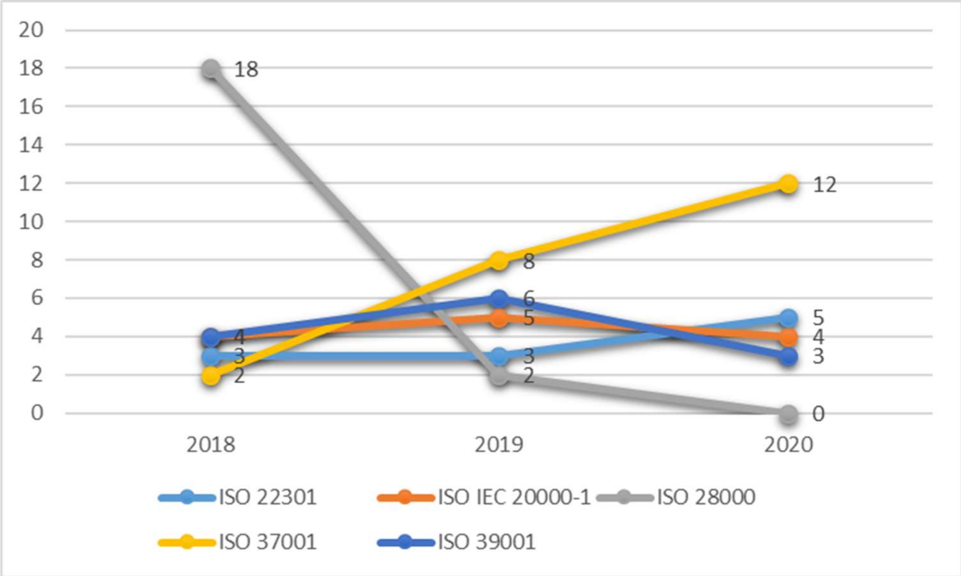

Figure 3 – The number of certificates awarded to educational organizations worldwide in 2018-2020 (within the 0-20 range), according to the "ISO Survey of certifications to management system standards - Full results 2018, 2019, 2020".

The third group encompasses standards with the lowest certification rates. Given the small amount of statistical evidence, it would be incorrect to draw any conclusions.

Figures 1-3 demonstrate varying tendencies of international standard certification among educational organizations. This result stems from opposing factors, with such positive factors as growing income rates, reduced costs, compliance with legal regulations, and higher customer satisfaction. On the other hand, negative factors (or constraints) include high implementation and maintenance costs, lack of human and other resources, uncertainty over certification results, insufficient government support, etc. (Cunha, Cabecinhas, Domingues, and Teixeira, 2020).

Standardized management systems, particularly QMS, are considered the principal enabler of educational organizations' sustainable development and compliance with the ESG criteria.

The COVID-19 pandemic became a challenge for educational organizations all over the globe. Due to public health restrictions imposed in many countries, educational institutions had to look for new ways to provide their services, prioritizing ICT-based distance learning formats. That boosted the application of digital technologies in education, with computer equipment and software becoming more commonly used and faculty members increasing their ICT competence.

Digitalization is considered an essential element of QMS development. The Digital Quality Management notion has been introduced, understood as the application of digital technologies to Quality Management impacting its tools, methods, and systems both at a technical and human level (Carvalho, Sampaio, Rebentisch, and Oehmen, 2020).

Artificial intelligence methods largely contribute to the digitalization of educational organizations. Those methods are most commonly used for data analysis, as provisioned by ISO 9001:2015 requirements.

There are numerous definitions of artificial intelligence (Stashkov, 2013; Morhat, 2018) and AI-related concepts, i.e., Machine Learning (IBM, 2017), Data Mining (Rafalovich, 2014), and Big Data (Mayer-Schönberger & Cukier, 2014). For example, one definition describes artificial intelligence as the science of making intelligent machines and computer programs that can perform functions previously considered to be human prerogative (Kalinin, 2018).

The following classes of AI methods can be distinguished:

- KNeighborsClassifier - the multi-dimensional classifier that assigns the studied object to the category the closest ones belong to, according to the set conditions (e.g., Euclidean metric).
- SVC - the multi-dimensional classifier based on creating a hyperplane with maximum distance from the initial vectors.
- RandomForestClassifier - the classifier using totalities of "decision tree" algorithms. Assignment of the object to a specific category depends on the number of trees that selected it (Dzedik and Chigirinskaya, 2018).

From the standpoint of AI application by educational organizations, neural networks and their multiple variants deserve special attention (Rojas, 1996)

RESEARCH METHODOLOGY

This study has analyzed the data on educational organizations' global functioning, collected directly by authors or taken from public sources. It also provides a retroactive overview of ISO development since 1987 (when the first standard of this type was issued), accompanied by quantitative and graphical analysis of data on educational organizations' certification for compliance with various international standards. The study has assessed the impact of the COVID-19 pandemic on educational organizations and their development; it makes conclusions on the consequent abrupt digitalization of education and the potential for applying AI methods. The study provides an overview of AI entity classes and an approximate algorithm that forecasts enrollment results based on previous campaigns. The algorithm uses AI methods and the AI application matrix for education levels and the main processes of the educational organization.

RESULTS

The classes listed above can address various data analysis tasks and forecast several indicators of the educational institution, such as enrollment results, student performance, and employment of graduates. For example, let us analyze the task of forecasting enrollment opportunities of an applicant for a bachelor's degree. Fig. 4 provides the algorithm for this task.

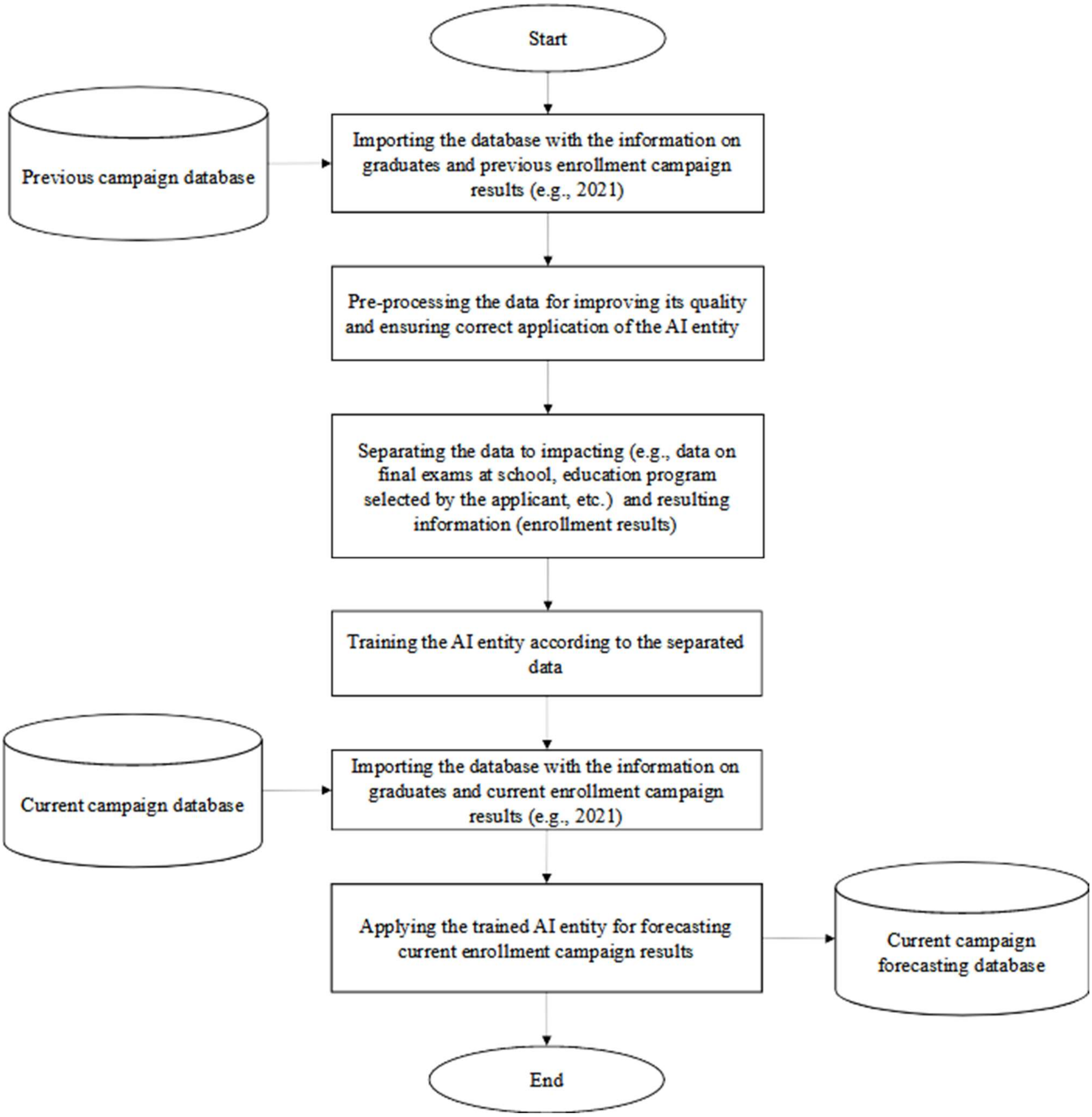

Figure 4 – Approximate algorithm for analyzing the data on applicant enrollment during previous campaigns and forecasting the current campaign results via AI methods (Elaborated by the authors)

Those AI method classes were tested to validate the algorithm presented in Fig. 4. Table 1 demonstrates the validation results.

Table 1 – AI classes validation results

AI method class	Accuracy of AI-based forecasting of bachelor's degree enrollment (in comparison with actual enrollment results)
KNeighborsClassifier	0.51
SVC	0.47
RandomForestClassifier	0.56
Neural Network	0.67

Table 1 shows that the neural network class resolves those tasks most effectively. However, all entities presented above can be further optimized and improve their results.

The authors have analyzed the quality management systems of 24 higher education institutions in different countries and systematized their main educational processes into three main clusters, i.e., pool formation, student performance, and employment. The study has also defined the main education levels implemented by said institutions, i.e., secondary vocational education, bachelor's degree, master's degree, additional professional education, and postgraduate education. Those levels slightly vary depending on national regulations; in particular, the analysis covered the International Standard Classification of Education (ISCED, 2011). By generalizing the results of education level analysis and the potential scope of AI application to main clusters of educational organization's processes, it is possible to create the systemic matrix, demonstrated in Table 2.

Table 2 – Matrix of applying artificial intelligence methods to education levels and main processes of the educational organization

Education level	Scope of artificial intelligence application for various clusters of main processes
Secondary vocational education	Forecasting the applicant pool formation Forecasting student performance Forecasting the graduate employment
Bachelor's degree	Forecasting the applicant pool formation Forecasting student performance Forecasting the graduate employment

Master's degree	Forecasting the applicant pool formation Forecasting student performance Forecasting the graduate employment
Additional professional education	Forecasting the applicant pool formation Forecasting student performance Forecasting the graduate employment
Postgraduate education	Forecasting the applicant pool formation Forecasting student performance Forecasting the graduate employment

The analysis of Table 2 enables us to conclude that the main tasks AI can solve at all education levels involve forecasting the applicant pool formation, student performance, and graduate employment.

Before applying AI technologies, it is essential to address the issues of data quality and data protection, as they are relevant to students' personal data. The former requires several functions that transform data arrays before applying the AI entities, e.g., converting letter clusters to digital clusters, excluding the linearly dependent data, and normalizing the data. In the latter case, it is critical to safeguard students' personal data, for instance, by encoding the data while simultaneously protecting primary arrays, coding algorithms, and intermediate data clusters from unauthorized access.

Forecasting the results of applicant pool formation precedes the direct educational process. For better resource management, the educational organization needs to anticipate the distribution of applicants by degree programs. Statistical data on previous campaigns can be divided into two categories. The impacting statistics comprise the results of applicant review, based on applicants' final exams relevant for their degree program, identification of schools they graduated from, etc. The resulting statistics comprise the application outcome (enrolled/ not enrolled) and the degree program. The following steps involve applying the preselected AI entity class, finding its optimal configuration parameters (e.g., the number of neural network layers), and training the entity based on the available data (categorized as impacting or resulting statistics, educational or testing samples, etc). After that, the AI entity can forecast the results of current enrollment campaigns.

The task of forecasting student performance is resolved similarly. In this case, the impacting statistics comprise interim assessment results (e.g., weekly or monthly), class attendance, other performance assessment methods, and information on student engagement in academic, volunteer, and other activities. The resulting statistics can demonstrate semester performance results.

Graduate employment forecasts also have much in common with the applicant pool and student performance forecasts. Its impacting statistics involve the data on degree programs, exam results, graduates' engagement in academic, volunteer, and other activities, the information on work placement results, additional qualifications, and acquired soft skills. For the resulting statistics, it is possible to use the information on the graduate's employment over a certain period (e.g., employment/unemployment within the first year after graduation), the relation between the job position and the educational program, salary size, etc.

Among educational organizations applying QMS, universities play a critical role. Apart from education, traditional universities fulfill three other missions, i.e., scientific research, personal development, and relationship with society. AI methods can facilitate the completion of those missions. The scientific mission, in particular, can be incentivized by resolving the following tasks:

- Forecasting the efficiency of academic events.

- Forecasting the outcome of engaging in competitions that fund scientific activities.

- Forecasting the publishing potential of scientific activities, etc.

Applying AI methods to the third mission is more challenging: unlike education and scientific activities (that deliver tangible results, e.g., enrolling in a master's degree or winning a scientific grant), individual traits that result from personal development can hardly be described and measured. However, further development of AI methods may eventually solve this issue.

Apart from those three missions that define the structure of main university activities, there are also administrative and auxiliary processes. In their case, the artificial intelligence usage is not specific to educational organizations and involves general tasks solved by software solutions used in various areas of the economy. Those tasks include planning, financial reporting, access control management, monitoring of compliance with PPE rules (e.g., use of face masks), etc.

CONCLUSIONS

The combination of various factors, such as the wide-range QMS application by educational organizations in compliance with international standards (e.g., ISO 9001 and ISO 21001) and the digitalization of education that rapidly intensified due to the COVID-19 pandemic, creates the window of opportunities for applying AI methods to main processes of educational organizations on all levels. That facilitates accurate forecasting and, as a result, enhances the management and sustainable development of educational organizations. The study defines the main direction for AI introduction to administrative, scientific, educational, auxiliary, and other processes; it analyzes how artificial intelligence can improve process efficiency. AI application addresses numerous tasks on all education levels enabling it to forecast applicant pool formation, student performance, and graduate employment.

Some factors limit the results of this study, including the time it takes for the ISO to publish its statistics on international certification. For instance, as of 2022 (when the work on this paper was in progress), the most recent data is for 2020 only. Another constraint is the relative hesitance of higher education institutions to disclose information on the structure and functioning of their management system.

Several higher education institutions have already adopted the results of this study (e.g., the algorithm demonstrated in Fig. 4) for developing specialized AI-based software to facilitate their management system efficiency.

Some issues remain unsolved, such as defining methods and benchmarks for assessing AI efficiency, integrating local AI applications to a unified structured system, and others. Addressing those tasks will become the objective for further research by the authors of this paper.

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REFERENCES

Carvalho, A. M. D., Sampaio, P., Rebentisch, E., and Oehmen, J. (2020). Technology and quality management: A review of concepts and opportunities in the digital transformation. International Conference on Quality Engineering and Management, pp. 698-714.

Celik, B., Ölcer, O. H., (2018). The Effect of ISO 9001 Quality Management System on Education Institutions (A Case Study of Ronaki Duhok Education Company in Iraq). *Int'l Journal of Management Innovation Systems*, 3(1), p. 6. doi: 10.5296/ijmis.v3i1.13596.

Cunha, A., Cabecinhas, M., Domingues, P. and Teixeira, V. (2020). ISO 14001 standard: Benefits, Motivations and Difficulties throughout the Implementation Process. International Conference on Quality Engineering and Management, pp. 363-374.

Doherty, G.D. (1995) BS 5750 Parts 1 and 2/ISO 9000 (series); 1987 and education – do they fit and is it worth it? *Quality Assurance in Education*, 3(2), pp. 3-9. doi: 10.1108/09684889510093488

Dzedik V. A., Chigirinskaya N.V. (2019) Application of Python Software Environment for Analyzing the Systems of Quality Management with the Use of Machine Teaching Methods. *Perspectives on the use of New Information and Communication Technology (ICT) in the Modern Economy*

(Pyatigorsk, Russia, February 1, 2018) : Conference papers. Ed. by E. G. Popkova, V. N. Ostrovskaya ; Institute of Scientific Communications, Center for Marketing Initiatives, Pyatigorsk State University. Switzerland : Springer International Publishing AG (Part of Springer Nature), p. 573–584, available at: https://www.springer.com/gp/book/9783319908342 (accessed 10 April 2022).

Guerra, B.R.M., Ramos, A.F.J., Roque, G.R. (2020) Standard ISO 21001:2018's application to the quality of academic postgraduate programs. *Revista Cubana de Educación Médica Superior,* 34(1), pp. 1-17.

International Standard Classification of Education ISCED 2011, available at: http://uis.unesco.org/sites/default/files/documents/international-standard-classification-of-education-isced-2011-en.pdf (accessed 10 April 2022).

ISO 14001:2015 "Environmental management systems — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 21001 "Educational organizations — Management systems for educational organizations — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 22301:2019 "Security and resilience — Business continuity management systems — Requirements", International Organization for Standardization, Geneva, Switzerland.

ISO 28000:2022 "Security and resilience — Security management systems — Requirements", International Organization for Standardization, Geneva, Switzerland.

ISO 29990:2010 "Learning services for non-formal education and training — Basic requirements for service providers", International Organization for Standardization, Geneva, Switzerland.

ISO 37001:2016 "Anti-bribery management systems — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 39001:2012 "Road traffic safety (RTS) management systems — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 45001:2018 "Occupational health and safety management systems — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 50001:2018 "Energy management systems — Requirements with guidance for use", International Organization for Standardization, Geneva, Switzerland.

ISO 9001:2015 "Quality management systems — Requirements", International Organization for Standardization, Geneva, Switzerland.

ISO Survey of certifications to management system standards - Full results 2018, International Organization for Standardization, Geneva, Switzerland.

ISO Survey of certifications to management system standards - Full results 2019, International Organization for Standardization, Geneva, Switzerland.

ISO Survey of certifications to management system standards - Full results 2020, International Organization for Standardization, Geneva, Switzerland.

ISO/IEC 20000-1:2011 "Information technology — Service management — Part 1: Service management system requirements", International Organization for Standardization, Geneva, Switzerland.

ISO/IEC 27001:2013 "Information technology — Security techniques — Information security management systems — Requirements", International Organization for Standardization, Geneva, Switzerland.

Kalinin, N. V. (2018) Oblasti primeneniya iskusstvennogo intellekta [Artificial Intelligence Application]. *Innovacionnaya ekonomika i sovremennyj menedzhment*, No. 1, pp. 50-52.

Mashinnoe obuchenie [Machine learning]. *IBM*, available at: www.ibm.com/analytics/ru/ru/technology/machine-learning/ (accessed 10 April 2022).

Mayer-Schönberger, V., Cukier, K. (2014) Big Data. A Revolution That Will Transform How We Live, Work, and Think. Translated in Russian by Inna Gaidyuk. Moscow : Mann, Ivanov i Ferber, 240 p.

Morhat, P. M. (2018) K voprosu o pravovoy definicii termina «iskusstvenny intellekt» [Revisiting the legal definition of artificial intelligence]. *The Academic Journal of Moscow City University. Legal Sciences*, No. 2 (30), pp. 74-80.

Rafalovich, V. (2014) Data mining, ili Intellektualnyy analiz dannyh dlya zanyatyh: prakticheskiy kurs [Data mining or Intelligent data analysis for the busy: a practical course]. M.: "I-treid", p. 11.

Rojas, R. (1996) Neural Networks. Springer, Berlin. 502 p.

Shanaida, V., Vitenko, T., Droździel, P. Madleňák, R. (2019). The role of education and research in the learning process of university students. *Conference: 13th International Technology, Education and Development Conference*, pp. 535-542. doi:10.21125/inted.2019.0213.

Silaeva, V.V., Semenov, V.P. (2018) Internal Education Quality Assurance through Standardization of Educational Organization Management System. *Proceedings of the 2018 International Conference "Quality Management, Transport and Information Security, Information Technologies", IT and QM and IS*, pp. 70-73. doi: 10.1109/ITMQIS.2018.8525083

Stashkov, A. M. (2013) Filosofskoe ponyatie iskusstvennogo intellekta [Philosophical Concept of Artificial Intelligence]. *Formirovanie gumanitarnoy sredy v vuze: innovacionnye obrazovatelnye tehnologii. Kompetentnostny podxod*, Vol. 4, pp. 5-9.

Stimson, W. A., (2003) Better Public Schools With ISO 9000:2000. *Quality Progress*, September 2003, pp. 38-45.

Thonhauser, T., Passmore, D. L. (2006) ISO 9000 in Education: a comparison between the United States and England. *Research in Comparative & International Education,* Vol. 1, No. 2, 2006, pp. 156-173. doi: 10.2304/rcie.2006.1.2.156.

Integrated Management Systems in Industry 4.0: Literature Review

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ABSTRACT

Purpose: Management Systems (MS) are a global phenomenon, and their integration is justified by the benefits that they provide to organizations. Thus, the main purpose of this paper was based on the analysis of the existing literature, with a view to characterizing the current state of the art to understand the impact that Industry 4.0 (I4.0) will have on Integrated Management Systems (IMS).

Design/methodology/approach: For this study, exploratory bibliographic research was carried out to extract the most important ideas from the literature, to better understand the main concepts related to ISO 9001, ISO 14001, and ISO 45001, considering the fourth industrial revolution. The methodological basis used in this study followed the PRISMA guidelines and the research was carried out essentially through two databases, Scopus, and Web of Science.

Findings: The integration of MS will be one of the pillars of I4.0 and it aims to interconnect the different areas of an industry, whose objective is to extract data and information that will be used to carry out continuous improvements in the entire production process and in all the related support areas. This paper reviews, lists and organizes the different technological concepts and integration opportunities that have been explored within the scope of IMS in I4.0.

Research limitations/implications: Although this literature review is limited to the aforementioned databases, there is still not much information available regarding the focus of IMS in I4.0.

Originally/value: This study contributed to a better perception and systematization of the IMS considering the I4.0. It focuses on the motivation and importance of ISO certifications, related to quality (9001), environment (14001) and occupational health and safety (45001) in I4.0. Thus, the contribution of this work aimed essentially to provide information about possible benefits and difficulties that may occur due to the implementation of IMS in I4.0 context.

Paper type: Literature review.

Keywords: Integrated Management Systems; Industry 4.0; ISO 9001; ISO 14001; ISO 45001.

1. INTRODUTION

Research on the impact of I4.0 on IMS is still very limited and with this article we intend to review and integrate different concepts and examples existing in the literature, to understand the contributions of new technologies to IMS.

I4.0 created smart factories and created a new manufacturing paradigm based on the adoption of new technologies in relation to physical cyber systems, internet of things, internet of services, robotics, big data, cloud manufacturing and augmented reality (Frank et al., 2019). I4.0 has transformed industry value chains by combining embedded production system technologies with intelligent production processes to pave the way for a new era of business, where these technological revolutions will transform production and logistics processes into intelligent factory environments that will increase productivity and efficiency (Preuveneers & Ilie-Zudor, 2017).

Zhou et al. (2016) report on the strategic plan developed by Germany to implement an optimized transition from Industry 3.0 to I4.0 and in relation to the essential factors for efficient management, they disclose that large and complex systems will need to be managed efficiently through a didactic model built for management optimization (Zhou et al., 2016).

According to Sampaio et al. (2012), the integration of MS avoids the development of organizational "islands" between subsystems, causing a lack of communication and cooperation (Sampaio et al., 2012).

This research aims to present a synthesis of the main concepts, strategies, advantages, and disadvantages of IMS, based on I4.0, which were studied and analysed by different researchers.

2. RESEARCH METHODOLOGY

This study was carried out through a systematic literature review and the initial selection of research sources aimed to collect scientific works with high impact and citation rates, using the Scopus and Web of Science (WoS) databases. The choice of the WoS database was based on the fact that it covers indexed journals with an impact factor calculated such as the Journal Citation Report (Barbosa et al., 2021; Carvalho et al., 2013) and Scopus was chosen because it is the largest scientific knowledge base in the literature review (Barbosa et al., 2021; Morioka & Carvalho, 2016).

In terms of scientific research, although these two sources guarantee quality and relevance to any field of research, they leave out a few works that could provide different perspectives and valuable contributions to this literature review. Thus, in a second stage, recent works were included, with new research trends, limited impact, and non-academic perspectives. Google Scholar continues to be the most searched database by all and, considering its size, this was also included in the research.

The strategy used to choose the articles consisted of filtering by specific search keywords. In the first search, the keywords "quality", "environment", "safety", "industry 4.0" were applied as "Topic" in the WoS database and as "Article title, Abstract, Keywords'" in the Scopus database, resulting in 26 and 54 documents respectively, with a total of 80 articles. In the second research, the keywords "integrated management system", "industry 4.0" were applied as "Topic" in the WoS database and as "Article title, Abstract, Keywords'" in the Scopus database, resulting in 2 and 9 documents respectively, with a total of 11 articles. In the third search, the keyword "integrated management system" was used as a "Topic" in the WoS database and as "Article title, Abstract, Keywords'" in the Scopus database, resulting in 774 and 1566 documents respectively, with a total of 2340 articles. Due to the high number of articles obtained, a filtering was made taking into account the most recent articles (1) and the articles classified as "Review" (2), so in the years 2021 and 2022 (1) the sample was reduced to 48 articles in the WoS base (36 results referring to 2021 and 12 results referring to 2022) and for 117 articles in the Scopus base (91 results referring to 2021 and 26 results referring to 2022) and in filtering as “Review”, the sample was reduced to 11 articles in the WoS database and 80 articles in the Scopus database. This analysis is summarized in Figure 1.

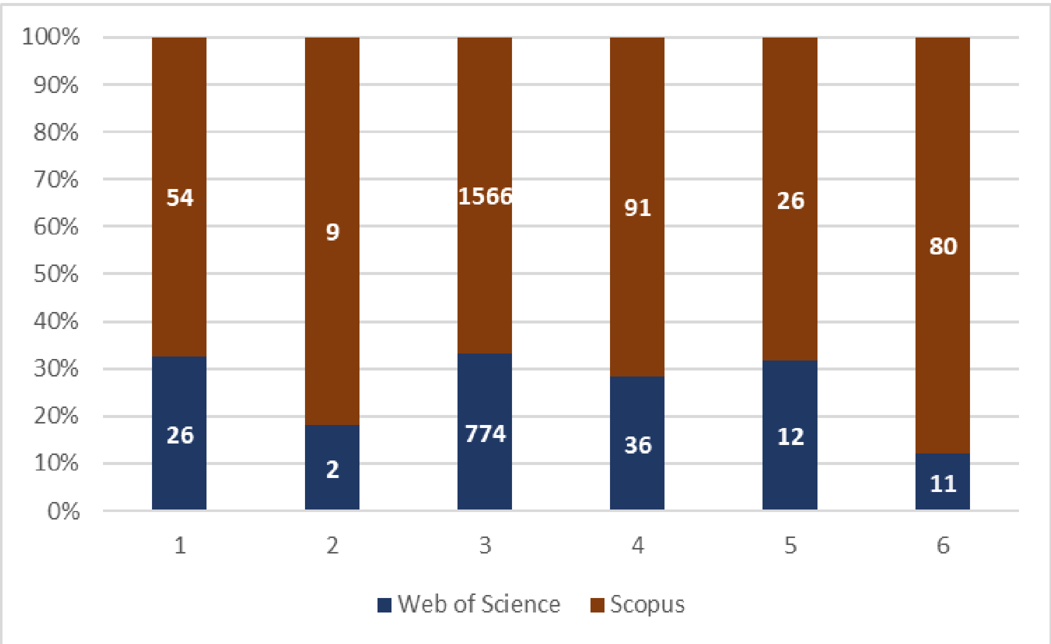

Figure 1: Summary of filtering found articles.

Finally, we proceeded to the content analysis of the articles that include the sample to identify the main factors that will affect an IMS in I4.0.

3. LITERATURE REVIEW

With the Fourth Industrial Revolution, also known as "Industry 4.0", the need arose to renew the structures that managed organizational processes, making them able to face changes. The adoption of certified quality, environment, health and safety MS has the potential to be the key that supports organizations during their evolution and to be a successful approach towards sustainable development.

3.1. Integrated Management Systems

According to Ribeiro et al. (2017), according to ISO, standardized MS provide a model to follow when setting up and operating a MS. All ISO standardization results from a global agreement of experts and therefore offers the benefit of knowledge, experience, and good global management practices. Standardized MS can be applied in any organization, large or small, whatever the product and/or service and sector of activity (Ribeiro et al., 2017).

In order to design competitive advantages and achieve sustainable development, many organizations implement Quality Management Systems (ISO 9001), Environmental Management Systems (ISO 14001) and Occupational Health and Safety Management Systems (ISO 45001), which are have become a widespread practice in recent years around the world (Trierweiller et al., 2014).

With the revisions of the ISO 9001 and ISO 14001 standards published in 2015 and with the new ISO 45001 standard in 2016, it's possible to conclude that research in IMS isn't just an academic study, but a step necessary to implement them properly. The successive drafts published throughout the review process suggest that the new reviews will require companies to have a 360° view taking into account the context in which they develop their activity, an integrative concept (risk-based approach) and a high-level structure that is a common set of requirements that allow them to be easily integrated (Arora, 2018; Domingues et al., 2017; Thaís Vieira Nunhes et al., 2019).

An IMS is defined as a single set of processes sharing a single fund of human resources, information, materials, infrastructure, and financial resources to achieve a set of objectives related to satisfying a variety of stakeholders. IMS started with the publication of the ISO 9001 (Quality Management System) in 1987, after which the ISO 14001 (Environmental Management System) was introduced in 1996 and OHSAS 18001 in 1999 (currently the ISO 45001, Occupational Health and Safety Management System, in 2016), and then different similar management systems emerged (Nunhes et al., 2016; Thomé et al., 2016).

According to the research work developed by Ribeiro et al. (2017), the future of the implementation of MS will be through the integration of an efficient IMS. Despite the benefits of integration, challenges inherent to this approach persist, namely regarding the evolution of human and financial resources. The authors concluded that organizations are more optimistic and begin to see a future with less difficulties in the integration process, however, when asked about future difficulties, they reported others similar to the current ones and only 25% admitted less difficulties (Ribeiro et al., 2017).

Currently, the main difficulties in terms of integration are lack of human resources with adequate training and knowledge, lack of involvement of top management, resistance to change, lack of financial resources. According to the organizations involved in the study, the greatest difficulties in the medium term will continue to be the lack of resources, although they are more optimistic, since the number of responses without difficulties has increased. The future trend for many management systems is full integration leading to an IMS (Ribeiro et al., 2017).

Figure 2 illustrates a Venn diagram that shows that all MS are interconnected, having common and specific elements.

Figure 2: Venn diagram applied in Certifiable Integrated Management Systems.

Recently, the work of Abisourour et al. (2020), who propose a framework to provide an adequate alignment of the objectives of IMS and strategic management using value stream mapping and cost implementation tools and Algheriani et al. (2019) who developed an integrated risk approach.

The ideas of gurus such as Deming, Juran, Crosby and Ishikawa are the foundations of the Total Quality Management (TQM) movement, whose roots are intertwined in four premises: quality, people, organizations, and leadership. TQM is the basis of current management models, with continuous improvement being an essential element and a critical criterion in all MS, certificates and related benefits (Sanchez-Ruiz et al., 2019; Santos & Martins, 2020).

According to the study of Algheriani et al. (2019), in recent years, the most important factors that encourage organizations to implement the various MS are business pressure, government regulations and laws, competitiveness, public pressures on environmental protection due to pollution, and health and safety risks of workers and customer satisfaction. Such factors required organizations to implement international standards in order to limit them, such as the implementation of ISO 9001 whose main objective is the effective management of risks that can adversely affect the quality of products, ISO 14001 that aims to control risks that can endanger the environment and ISO 45001, which aims to reduce the risk of accidents at work (Algheriani et al., 2019).

Algheriani et al. (2019) developed a risk model for the IMS that has several characteristics that help organizations in its application by the following common approaches: risk-based thinking with risk management as an important factor in identifying, evaluating, and handling of common risks in all standardized systems. The process approach is used to manage and evaluate the performance of each process in the model and the Deming cycle operates as a continuous improvement cycle, ensuring that processes are adequately resourced, well managed and that opportunities for improvement are determined. This model can be implemented in any organization, regardless of type, size and product, as it integrates the most common international standards used by most organizations worldwide (Algheriani et al., 2019).

3.2. Industry 4.0

The concept “Industry 4.0” is applied to a set of rapid transformations in the design, manufacture, operation and service of industrial systems and products. The designation 4.0 means that this is the fourth industrial revolution in the world, the successor to three great industrial revolutions that caused quantum leaps in productivity and changed the lives of people all over the world (Davies, 2015; Khanzode et al., 2021). In other words, the I4.0 is transforming industry value chains by combining embedded production system technologies with intelligent production processes to pave the way for a new age of business by increasing productivity and efficiency (Chiarini et al., 2020; Santos & Martins, 2020).

So far, the three industrial revolutions have led to paradigm shifts in the industrial domain: mechanization and steam power; mass production with assembly lines and automation through the use of information technology (Thoben et al., 2017; Xu et al., 2018). However, in recent years, across the world, practitioners, together with researchers and policymakers, have increasingly advocated a continuing fourth industrial revolution better known as I4.0.(Rafael et al., 2020). Figure 3 depicts the four industrial revolutions, the evolution of the industry from 1784 to the present (Szada-Borzyszkowski, 2022).

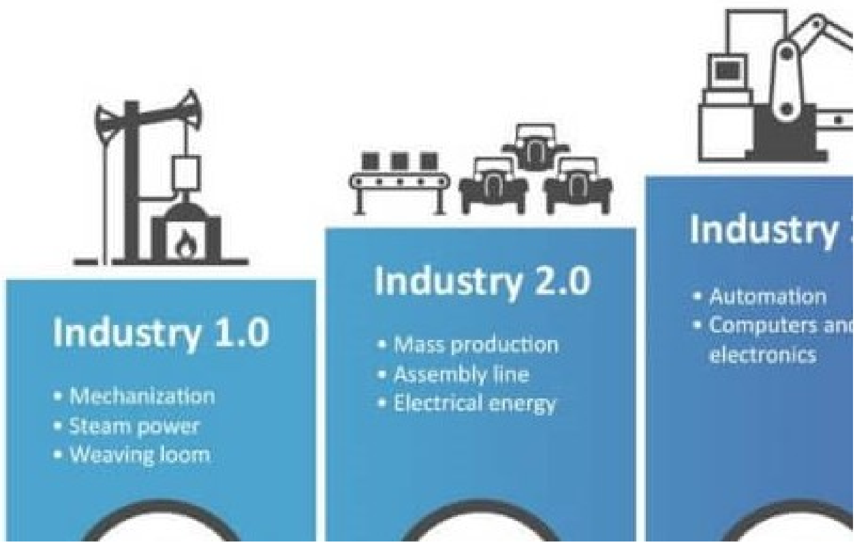

Figure 3: Industrial evolution.

Fonte: Szada-Borzyszkowski (2022).

For Silva et al. (2020), I4.0 describes the fourth industrial revolution, which leads to smart, connected and decentralized production, representing a new level of organization and regulation of the entire value chain of a product throughout its life cycle. Advances in data storage and new computing capabilities, along with developments in technologies such as computational intelligence, automation and robotics, additive industry, and human-machine interaction, are triggering innovations that change the nature and content of manufacturing itself. Industry leaders and researchers agree that digital industry technologies will transform all aspects of value chain industry systems (Silva et al., 2020).

3.2.1. What will change with Industry 4.0?

In the industry of the future, humans and machines will be able to work together. For a specific task, individuals can be quickly directed to the right tool that will automatically know the next step of the task and define the correct calibration for the specific part that the individual intends. Smart tools will also be able to record the operation, to ensure quality control and eliminate manual login (Davies, 2015).

According to Westkämper (2014), the four major topics for the development of industry are illustrated in Figure 4:

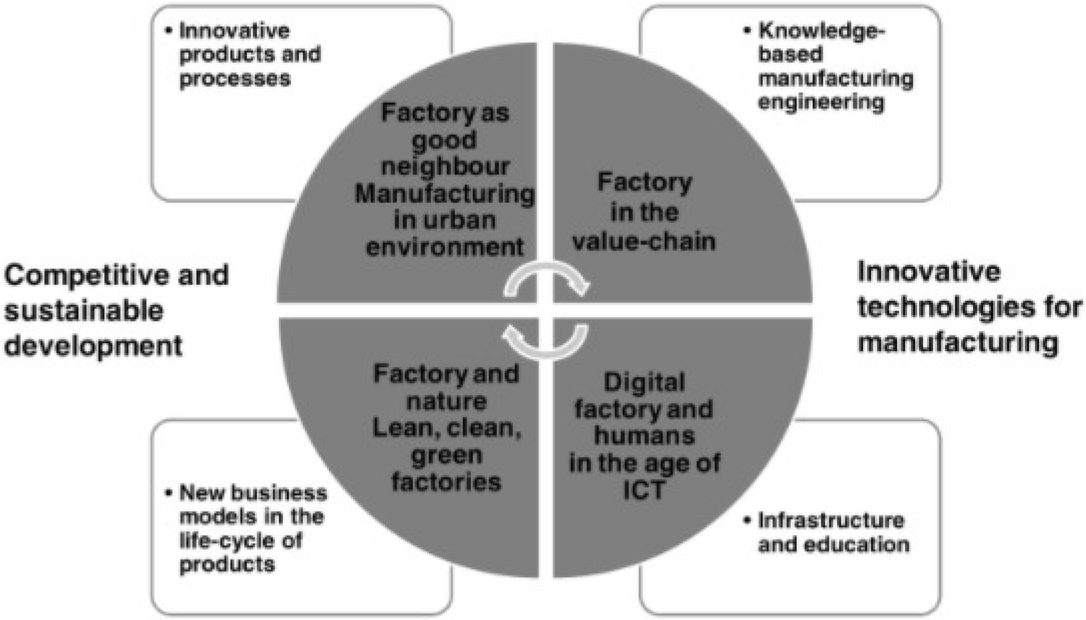

Figure 4: The four main topics for the industry of 2030.

Fonte: Adapted Westkämper (2014).

Human-machine collaboration is considered essential for the success of companies with high productivity demanded by competition, through the use of I4.0 principles (Lorenz et al., 2015; Romero et al., 2016).

4. RESULTS AND DISCUSSION

In this chapter, it will be done an analysis of the main highlights taken from the studied articles.

According to Dahlin & Isaksson (2017) the main advantages of IMS are document reduction, cost reduction, operational improvements and better communication between departments. The main disadvantages are lack of human resources, lack of employee motivation, differences in standards and complexity in integration (Dahlin & Isaksson, 2017).

In the research developed by Nawaz & Koç (2018), sustainability management has been carried out as a distinct concept, rather than the IMS existing. Sustainability has increased in the business world, and it has been one of the strengths of companies, since economic, quality, environment, health and safety and social challenges can be managed through the application of this framework. The operational advantages of the proposed framework include stakeholders involvement, greater transparency, adaptability, development and evaluation of organized systems (Nawaz & Koç, 2018).

According to the study by Nunhes et al. (2019), the words "sustainability" and "sustainable development" are classified as emerging terms in the context of the IMS, giving rise to the same tendency to link IMS with sustainable development approaches (Thaís Vieira Nunhes et al., 2019).

Barbosa et al. (2021) mention that many companies, regardless of nationality, follow the guidelines of integration MS and this procedure brings many benefits, such as improving the organization's image for the stakeholders, promote sustainable development, improve the quality of working life, increase the competitiveness of the corporation, and improve workplace health. The authors argue that IMS bring internal benefits (they can improve performance and reduce organizational costs, as well as how to improve the work environment and stakeholders satisfaction) and external (improve the interaction between the company and entities such as the government, the competition and society) (Barbosa et al., 2021).

The research carried out by Mora-Contreras (2019) concludes that the IMS implementation methodology supports the fulfilment of the organizational model, avoids redundancies and duplicities in the IMS implementation, contributes to the establishment of effective processes and procedures for the creation and control of reliable documents. Thus, these changes can be summarized in the reduction of time and errors during the preparation of public deeds, the elimination of operational control that is part of ineffective bureaucracy to increase the effectiveness of said activity, the reduction of paper consumption and the reduction of associated costs to document management (Mora-Contreras, 2019).

Table 1 summarizes the main advantages and barriers associated with the IMS and the research of Ispas & Mironeasa (2022) will be used as a basis as it‘s a very complete work.

Table 1: Main advantages and barriers associated to IMS by different authors.

Fonte: Adapted Ispas & Mironeasa (2022).

Advantages	**Barriers**
Reduction of duplicate and written documentation. Simplification of system procedures. Implementation of management systems in a shorter time. Reducing the time and unifying the audits. Unifying and reducing the time the training. An organization that already has an IMS has an advantage over an organization that doesn´t have an IMS. Reducing organization costs. Restructuring human resources, the strategies of organizations, the allocated financial resources, the definition of responsibilities, the organization's processes and communication. Social advantages. Customer satisfaction. Improving the image of the organization and the quality of products or services, the environment and the human health and safety.	The lack of information, training, communication with the work team, employees motivation for IMS implementation, ISO promotion of IMS integration. Variety of MS standards and purpose. Different cultures/personalities obstruct the integration of MS. The fear of failing in the IMS implementation. Employees aren't aware of the new changes and lack the concept of integration. Inadequate benefits from IMS implementation. Permanent updating of regulations. Lack of experience of the management representative in implementing the IMS. Underestimation of requirements from a certain MS.

5. CONCLUSION

This study presents an analysis of the models proposed by different researchers, providing an overview of the most used MS and at this stage it was important to mention the advantages and barriers associated with the implementation of IMS.

One of the concepts of I4.0 is to have a greater integration between the processes and sectors of the factories, exchanging information in a faster and more efficient way for a faster decision making to increase productivity, reduce losses, optimize resources, and take digital transformation into industries. Recent investigations indicate that Artificial Intelligence will guide international trade at the end of this decade, getting involved in the production and distribution chain of products, being necessary to study the impact that this new technological revolution will have on IMS to categorize new risks and develop new assessment methods.

Sustainable development is one of the current and emerging topics linked to IMS. Many stakeholders question companies on this topic and there is a trend in the search, collection, and storage of information in this sense and whoever responds in this area is already the manager of MS.

It's important to mention that the number of studies with a quantitative approach in measuring the benefits arising from the IMS is still low, and no studies were identified that mapped and quantitatively analysed the intensity of the impacts of each MS (quality, environment and occupational health and safety) when implemented in an integrated manner. This indicates an opportunity for the development of additional studies, where it's necessary to develop more theoretical and practical research (with case studies) to determine what is the real impact of the IMS considering the fourth industrial revolution.

REFERENCES

Abisourour, J., Hachkar, M., Mounir, B., & Farchi, A. (2020). Methodology for integrated management system improvement: combining costs deployment and value stream mapping. *International Journal of Production Research*, *58*(12), 3667–3685. https://doi.org/10.1080/00207543.2019.1633482

Algheriani, N. M. S., Majstorovic, V. D., Kirin, S., & Spasojevic Brkic, V. (2019). Risk model for integrated management system. *Tehnicki Vjesnik*, *26*(6), 1833–1840. https://doi.org/10.17559/TV-20190123142317

Arora, S. (2018). *ISO 9001:2015 and beyond - Preparing for the next 25 years of quality management standards*. https://www.linkedin.com/pulse/iso-90012015-beyond-preparing-next-25-years-quality-saloni-arora-

Barbosa, A. de S., Silva, L. B. da, Souza, V. F. de, & Morioka, S. N. (2021). Integrated Management Systems: their organizational impacts. *Total Quality Management & Business Excellence*, 24. https://doi.org/10.1080/14783363.2021.1893685

Carvalho, M. M., Fleury, A., & Lopes, A. P. (2013). An overview of the literature on technology roadmapping (TRM): Contributions and trends. *Technological Forecasting & Social Change*, *80*, 1418–1437. https://doi.org/10.1016/j.techfore.2012.11.008

Chiarini, A., Belvedere, V., & Grando, A. (2020). Industry 4.0 strategies and technological developments. An exploratory research from Italian manufacturing companies. *Production Planning and Control*, *31*(16), 1385–1398. https://doi.org/10.1080/09537287.2019.1710304

Dahlin, G., & Isaksson, R. (2017). Integrated management systems - interpretations, results, opportunities. *TQM Journal*, *29*(3), 528–542. https://doi.org/10.1108/TQM-01-2016-0004

Davies, R. (2015). Industry 4.0. Digitalisation for productivity and growth. *European Parliamentary Research Service*, *September*, 10.

Domingues, P., Sampaio, P., & Arezes, P. M. (2017). Management systems integration: survey results. *International Journal of Quality and Reliability Management*, *34*(8), 1252–1294. https://doi.org/10.1108/IJQRM-03-2015-0032

Frank, A. G., Dalenogare, L. S., & Ayala, N. F. (2019). Industry 4.0 technologies: Implementation patterns in manufacturing companies. *International Journal of Production Economics*, *210*, 15–26. https://doi.org/10.1016/j.ijpe.2019.01.004

Ispas, L., & Mironeasa, C. (2022). The Identification of Common Models Applied for the Integration of Management Systems: A Review. *Sustainability*, *14*(3559), 1–16. https://doi.org/10.3390/su14063559

Khanzode, A. G., Sarma, P. R. S., Mangla, S. K., & Yuan, H. (2021). Modeling the Industry 4.0 adoption for sustainable production in Micro, Small & Medium Enterprises. *Journal of Cleaner Production*, *279*, 123489. https://doi.org/10.1016/j.jclepro.2020.123489

Lorenz, M., Rüßmann, M., Strack, R., Lueth, K. L., & Bolle, M. (2015). Man and Machine in Industry 4.0 - How Will Technology Transform the Industrial Workforce Through 2025? *The Boston Consulting Group*, 22. https://image-src.bcg.com/Images/BCG_Man_and_Machine_in_Industry_4_0_Sep_2015_tcm9-61676.pdf

Mora-Contreras, R. (2019). Sistemas integrados de gestión de las normas ISO 9001 e ISO 30301 en el contexto notarial colombiano. *Journal of Management and Economics for Iberoamerica*, *35*(151), 203–218. https://doi.org/10.18046/j.estger.2019.151.3248

Morioka, S. N., & Carvalho, M. M. de. (2016). A systematic literature review towards a conceptual framework for integrating sustainability performance into business. *Journal of Cleaner Production*, *136*, 134–146. https://doi.org/10.1016/j.jclepro.2016.01.104

Nawaz, W., & Koç, M. (2018). Development of a systematic framework for sustainability management of organizations. *Journal of Cleaner Production*, *171*, 1255–1274. https://doi.org/10.1016/j.jclepro.2017.10.011

Nunhes, Thaís Vieira, Bernardo, M., & Oliveira, O. J. (2019). Guiding principles of integrated management systems: Towards unifying a starting point for researchers and practitioners. *Journal of Cleaner Production*, *210*, 977–993. https://doi.org/10.1016/j.jclepro.2018.11.066

Nunhes, Thais Vieira, Motta, L. C. F., & Oliveira, O. J. de. (2016). Evolution of integrated management systems research on the Journal of Cleaner Production: Identification of contributions and gaps in the literature. *Journal of Cleaner Production*, *139*, 1234–1244. https://doi.org/10.1016/j.jclepro.2016.08.159

Preuveneers, D., & Ilie-Zudor, E. (2017). The intelligent industry of the future: A survey on emerging trends, research challenges and opportunities in Industry 4.0. *Journal of Ambient Intelligence and Smart Environments*, *9*(3), 287–298. https://doi.org/10.3233/AIS-170432

Rafael, L. D., Jaione, G. E., Cristina, L., & Ibon, S. L. (2020). An Industry 4.0 maturity model for machine tool companies. *Technological Forecasting & Social Change*, *159*, 1–13. https://doi.org/10.1016/j.techfore.2020.120203

Ribeiro, F., Santos, G., Rebelo, M. F., & Silva, R. (2017). Integrated Management Systems: Trends for Portugal in the 2025 horizon. *Procedia Manufacturing*, *13*, 1191–1198. https://doi.org/10.1016/j.promfg.2017.09.194

Romero, D., Bernus, P., Noran, O., Stahre, J., & Fast-Berglund, A. (2016). The Operator 4.0: Human Cyber-Physical Systems & Adaptive Automation Towards Human-Automation Symbiosis Work Systems Conference. *IFIP Advances in Information and Communication Technology*. https://doi.org/10.1007/978-3-319-51133-7

Sampaio, P., Saraiva, P., & Domingues, P. (2012). Management systems: Integration or addition? *International Journal of Quality & Reliability Management*, *29*(4), 402–424. https://doi.org/10.1108/02656711211224857

Sanchez-Ruiz, L., Blanco, B., & Diaz, E. (2019). Difficulty in implementing continuous improvement – Rasch measurement analysis. *Business Process Management Journal*, *25*(6), 1228–1250. https://doi.org/10.1108/BPMJ-05-2017-0125

Santos, P. H. A., & Martins, R. A. (2020). Continuous improvement programs and industry 4.0: Descriptive bibliometric analysis. *International Conference on Quality Engineering and Management*, *2020-Septe*(September), 683–697.

Silva, E. R. da, Shinohara, A. C., Nielsen, C. P., De Lima, E. P., & Angelis, J. (2020). Operating digital manufacturing in industry 4.0: The role of advanced manufacturing technologies. *Procedia CIRP*, *93*, 174–179. https://doi.org/10.1016/j.procir.2020.04.063

Szada-Borzyszkowski, J. (2022). *Industry 4.0 – the industrial revolution*. https://sii.pl/blog/industry-4-0-the-industrial-revolution/

Thoben, K.-D., Wiesner, S., & Wuest, T. (2017). "Industrie 4.0" and Smart Manufacturing – A Review of Research Issues and Application Examples. *International Journal of Automation Technology*, *11*(1), 1–13.

Thomé, A. M. T., Scavarda, L. F., & Scavarda, A. J. (2016). Conducting systematic literature review in operations management. *Production Planning and Control*, *27*(5), 408–420. https://doi.org/10.1080/09537287.2015.1129464

Trierweiller, A. C., Gisi, M. F. S., Spenassato, D., Bornia, A. C., & Peixe, B. C. S. (2014). PROCESSO DE SELEÇÃO DE REFERENCIAL TEÓRICO: SISTEMAS DE GESTÃO INTEGRADOS. *XXXIV ENCONTRO NACIONAL DE ENGENHARIA DE PRODUCAO*, 18.

Westkämper, E. (2014). *Towards the Re-Industrialization of Europe: A Concept for Manufacturing for 2030* (1st ed.). Springer-Verlag Berlin Heidelberg. https://doi.org/10.1007/978-3-642-38502-5

Xu, L. Da, Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. *International Journal of Production Research*, *56*(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806

Zhou, K., Liu, T., & Zhou, L. (2016). Industry 4.0: Towards future industrial opportunities and challenges. *2015 12th International Conference on Fuzzy Systems and Knowledge Discovery, FSKD 2015*, 2147–2152. https://doi.org/10.1109/FSKD.2015.7382284

Benchmarking 10 Engineering Courses of the Federal University at Bahia, Brazil

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STRUCTURED ABSTRACT

Purpose - The main objective of this article was to find improvement factors for the 10 engineering courses offered at the Federal University of Bahia (UFBA) through benchmarking with the Federal University of Rio Grande do Sul (UFRGS).

Methodology – This paper is framed as Applied Research of a Case Study addressing a Quantitative and Qualitative Research. After studies about benchmarking and continuous improvement the benchmark was defined. The indicator chosen was ENADE over the evaluation cycles of the Preliminary Course Concept.

Findings – Analyzing 2019, the average Continuous CPC of the 8-engineering courses evaluated by UFBA was 3.237, while for the same courses at UFRGS the average was 3.483. This indicates that UFBA's engineering courses are 7.60% behind UFRGS courses. But between 2017 and 2019, the average Continuous CPC of EPUFBA’s courses showed a growth of 8.04%, while EPUFRGS showed a decline of 3,59%. To lever up the quality of the courses, the most important items to be improved are pedagogical organization; school's infrastructure, especially in technical laboratories; more postgraduate courses derived from each engineering; reviewing of the curriculum of all courses offered.

Research limitations – To deepen the analyses, it is intended to make visits to the courses that were used as benchmarks, an important part of benchmarking process.

Practical implications – The work will be of great value to improve the 10 courses studied, aiming at a better position in the next evaluation cycle of Enade, 2023**.**

Keywords: *Benchmarking, Engineering courses, UFBA, Improvement*.

Paper type: Case study

INTRODUCTION

In Brazil, the National High School Exam (Enem) was created in 1998, with the objective of evaluating students' school performance at the end of basic education. From then on, universities, both public and private, began to use this exam in place of the entrance exam, accepting students who have obtained the best grades. This leads these students to choose for the best evaluated courses, leaving the others with less qualified students, thus urging universities to seek to improve the evaluation of their courses.

This work, started in October 2018, is the result of the desire of the High Administration of the Polytechnic School of the Federal University of Bahia (EPUFBA) to improve the quality of the 10 engineering courses offered. A survey of the problems was carried out in the various departments, and more than 500 opportunities for improvement were pointed out. Four Committees were established to monitor the development of the work (Jesus *et al*. 2019) (Jesus and Dumet, 2019). A goal of obtaining a grade 4 in the evaluation carried out by the Federal Government was established and achieved by all courses at the end of 2019.

The current phase consists of the survey of the current stage of the 10 courses and comparison with benchmarks, that is, better courses scored nationally, aiming at a continuous improvement process. In this sense, the primary objective of this work was to find critical improvement factors for the 10 courses under discussion. After all, despite the good placements in relation to the total number of universities, an institution should always seek continuous improvement. One way to join this process is to study the main national indicators, analyzing the courses and learning from other institutions. A goal studied may be to establish a maximum score of 5 in all courses in the next ENADE assessment, in November 2023. It is also an objective to verify if the improvement rate of the UFBA engineering courses is higher than that of a benchmark, which is an important indicator proposed by Juran (1990).

LITERATURE REVIEW

Benchmarking

The research focuses on benchmarking based on the premise of this tool and its qualitative facet. After all, as defined by the National Quality Foundation (FNQ, 2015), benchmarking is a method of comparison between processes or similar products to investigate how others perform more effectively, aiming to implement improvements.

According to Stapenhurst (2009), benchmarking is a method of measuring and improving organizational performance by comparing with the best and the benefits of this method extend to numerous institutions and can promote relevant gains.
Also, according to the FNQ (2015), among the benefits of benchmarking are the incentive to new practices and the culture of monitoring results. The benchmarking process consists of 3 phases, considering the initial phase as preparation, which are identifying gaps and implementing improvements, as shown in Figure 1 (Stapenhurst, 2009).

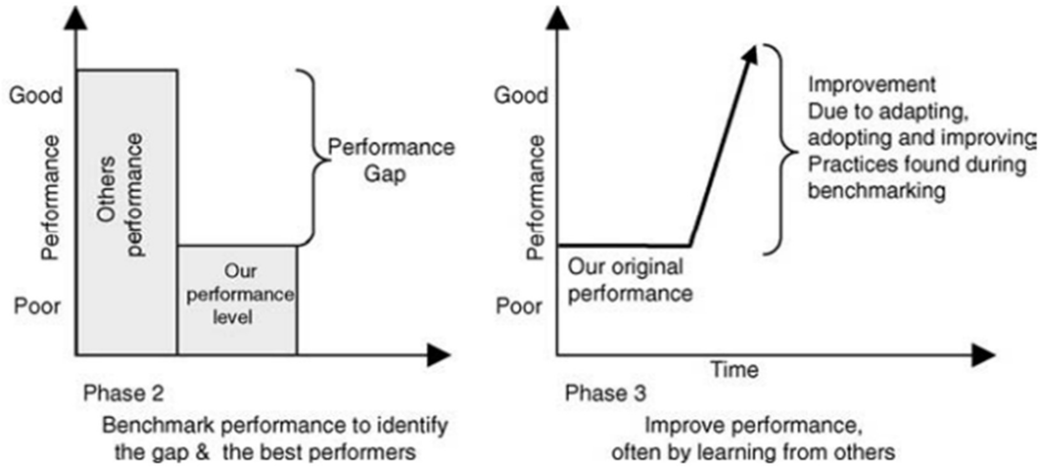


Figure 1 - Phases of benchmarking (Stapenhurst, 2009)

It is notorious the possibility of using benchmarking in public organizations, in which Public Institutions of Higher Education are inserted, which is the case of the UFBA. Historically, the Public University has been through challenging moments that question its actions, from the equity of the entry of students to the process of institutional evaluation. Therefore, the search for improvement is a path of transformation for these institutions (Carvalho and Souza, 2017).

Institutional Assessment in Brazil

Institutional evaluation in Brazil is not a recent issue, having gained greater notoriety in the 90s, with the considerable increase in Private Institutions of Higher Education. As a result, several proposals for evaluating institutions have emerged, covering topics such as courses, students and programs offered (Behenck *et al.*, 2019).
According to Pires and Araújo (2019), the design of this type of verification has as its central objective the continuous improvement of academic and administrative activities carried out by HEIs. Institutional evaluation is a systematic process that should promote

the judgment of institutional quality in relation to its goals and actions, as well as its social responsibility in favor of solidary and emancipatory knowledge.

Regarding the commitment to the community, evaluation is understood as something beyond regulation, acting as an instrument that aims to promote the democratic participation of the academic community in public life, based on political and ethical responsibility (Abramowicz and Lara, 2010).

It is possible to infer that evaluation is integrated into the pedagogical process, linked to all aspects that concern the life of the institution and its development, including teaching, research, and extension activities. Therefore, it must translate the evolution of the institutional identity, mining what has been done well through the improvement of projects, both in the institutional scope and in the undergraduate courses, giving visibility to the significant contributions to the community (Pires and Araújo, 2019).

From the growth of HEIs spread across the country and the broad debate on the subject, the National System of Higher Education Evaluation (SINAES) emerged, implemented by Law 10,861/2004. SINAES made institutional assessment mandatory, based on two stages: self-assessment, when the HEI itself assesses its institutional practices in relation to each course, and external assessment, to accredit, authorize and validate the work developed (Pires and Araújo, 2019).

Thus, institutional evaluation has gained vast importance with regard to higher education, ceasing to be an optional activity and becoming a necessary curricular component. After all, it allows HEIs, based on standardized criteria, to analyze their processes, measure their performance. and assess the achievement of goals. (Pires and Araújo, 2019).

Quality indicators of Higher Education in Brazil

In Brazil there are 2,608 Higher Education Institutions (HEIs), of which 2,076 colleges, 294 university centers, 198 universities and 40 Federal Institutes of Education and Federal Centers of Technological Education (MEC, 2020).

Based on the quality indicators provided by SINAES, it is possible to assess in a standardized way this amount of HEIs. The indicators were established, with the premise of being complementary in the evaluation of items such as teaching, research, extension, student performance, institution management, faculty and infrastructure, among others (MEC, 2009).

In this study, it is worth mentioning three of them, as they are the data sources chosen for comparison: General Course Index (IGC), Preliminary Course Concept (CPC) and

National Student Performance Exam (ENADE). All indicators are defined on a continuous scale (decimal numbers) ranging from 0 to 5. From these values, the general classification of the given indicator is defined, standardized in ranges from 1 to 5 and allows grouping the HEIs into scoring blocks and, consequently, similar status.

The main indicator is ENADE. The ENADE Concept necessarily evaluates undergraduate students through a test that investigates the learning of programmatic content scans of each area and the competencies acquired by the student during their training, in addition to a socioeconomic questionnaire. Each year ENADE is dedicated to a Triennial Evaluation Cycle. The areas of knowledge are divided into three groups. Each one is evaluated every three years (INEP, 2020).

The CPC, in turn, is composed of four components that are intended to evaluate the quality of undergraduate courses, they are: ENADE Concept; Student Questionnaire at ENADE; Value added by the course to the development of the graduating students (IDD) and the Profile of the Faculty (Work Regime and Titration). CPC also occurs in triennial evaluation cycles (INEP, 2020).

Finally, there is the IGC, which is the general indicator for each university. It is calculated annually and considers the following aspects: average CPC of the last three years; average of the concepts of evaluation *of stricto sensu* graduate programs; distribution of students between different levels of education (INEP, 2020).

UFBA

The Federal University of Bahia started 214 years ago, in 1808, when the School of Surgery of Bahia was established by Prince Regent Dom João IV. This was the first university course in Brazil. The adoption of the name university was in 1950, aggregating all the existing courses at the time.

The Polytechnic School of UFBA (EPUFBA), a unit that holds the university's engineering courses, is in Salvador, Bahia, Brazil. Founded in 1897, it currently has 125 years of history. According to the Annual Activity Report of 2021 (EPUFBA, 2021), the Polytechnic has 4,886 undergraduate students and approximately 1,000 graduate students. EPUFBA has 183 professors distributed in seven departments: Department of Electrical Engineering and Computing (DEEC), Department of Mechanical Engineering (DEM), Department of Chemical Engineering (DEQ), Department of Transportation Engineering and Geodesy (DETG), Department of Materials Science and Technology (DCTM), Department of Construction and Structures (DCE) and Department of Environmental

Engineering (DEA). These seven departments offer 11 undergraduate courses, 10 being engineering.

Table 1 - Year of implementation of current engineering courses at the UFBA Polytechnic School

COURSE	IMPLEMENTATION YEAR
Civil engineering	1939
Computer engineering	2008
Surveying engineering	2009
Control and automation engineering	2008
Mining engineering	1977
Production engineering	2008
Electric engineering	1941
Mechanical engineering	1968
Chemical engineering	1942
Sanitary and environmental engineering	1994

In addition, being the largest unit of the Federal University of Bahia, EPUFBA has eight master's degrees (academics and professionals), six doctorate's degrees, several specialization and extension courses and more than 40 research groups. However, despite this vast structure, EPUFBA has much to improve to have its 10 engineering courses performing among the best in the country.

To analyze the scenario of UFBA among the HEIs (Higher Education Institutions) of the country, the appropriate indicator is the IGC, mentioned above. The last balance sheet occurred in 2019, since COVID-19 pandemic affected studies, research, and face-to-face evaluations. According to this, the Federal University of Bahia was ranked 55th out of 2,069 Higher Education Institutions, with a continuous IGC of 3.846. Compared only with public universities, UFBA ranks 19th among 106 universities.

UFRGS

The Federal University of Rio Grande do Sul (UFRGS) began in 1895, with the foundation of the School of Pharmacy and Chemistry. The university, located in the state of Rio Grande do Sul currently has 30 academic units. The School of Engineering of UFRGS has approximately 8,500 students, 5,000 under graduation. Its infrastructure has 10 teaching laboratories and more than 80 research laboratories spread over 16 buildings. (UFRGS, 2018).

The Engineering School has a total of 13 undergraduate courses. Ten of them are offered directly in one Unit: Civil Engineering, Mechanical Engineering, Electrical Engineering, Chemical Engineering, Mining Engineering, Materials Engineering, Metallurgy Engineering, Production Engineering, Control and Automation Engineering and Energy Engineering. In addition to these courses, there are also interdisciplinary ones, which cover more than one Academic Unit, such as Environmental Engineering in partnership with the School of Engineering and the Institute of Hydraulic Research (IPH); Computer Engineering, in partnership with the Institute of Informatics and Physical Engineering, in partnership with the Institute of Physics. (UFRGS, 2018). Table 2 compares general datas from UFRGS and UFBA.

Analyzing its panorama within the Brazilian HEIs, UFRGS achieved great performance in 2019. It obtained the Continuous IGC of 4.301, which led to the 12th place among all 2069 Brazilian HEIs. Considering only public universities, it occupied the 3rd place of 106 HEIs.

Table 2 - Comparison of the structure of the UFBA and UFRGS Engineering Schools*

ITEM	UFBA	UFRGS
Number of undergraduate courses offered	11	13
Number of undergraduate students	4885	5000
Number of graduate students	1000	3500
Number of professors	183	227

*Approximate values of the last institutional records

RESEARCH METHODOLOGY

This document is framed as Applied Research of a Case Study, since it seeks to generate knowledge for practical application aimed at solving specific problems, involving local interests. In addition, it also deals with a Quantitative Research, because it uses statistical resources and techniques, and a Qualitative Research because the natural environment is the direct source for data collection (Silva and Menezes, 2005).

This case study arises from the need to understand how the engineering courses of the Polytechnic School of the Federal University of Bahia (EPUFBA) are situated in an overview of Brazil. The case study generally evaluates qualitative data and contributes significantly to the understanding of several phenomena, such as organizational ones (Yin, 2001).

In view of this, after studies on the topic of benchmarking and continuous improvement, the first action taken was to define the benchmark, that is, the university to be compared with UFBA. In this case, the choice was the Federal University of Rio Grande do Sul (UFRGS), based on three defined criteria.

First, UFRGS is among the 5 best universities in the country in several rankings released annually, in addition to the ENADE, such as the Folha University Ranking (RUF), which is published by the well-known national magazine Folha de São Paulo. Second, it is also a federal public university, ensuring similarity. Federal universities are created by law and subsidized by the federal government, with qualifications for self-management and other prerogatives.

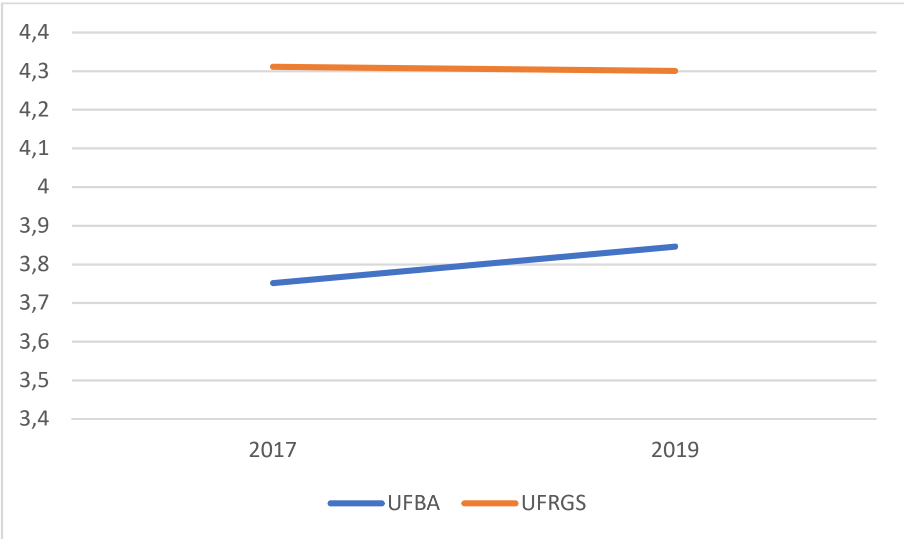
Finally, it was considered which university met the previous criteria and would be in a state with conditions that are minimally like those of Bahia - such as population and number of counties. After that, it was concluded, in a qualitative way, that the university to be considered would be the UFRGS, located in the state of Rio Grande do Sul.

Based on this definition, the case study was ruled on the analysis of the performance of these two universities throughout the evaluation cycles of the Preliminary Course Concept, an important indicator of the quality of higher education in Brazil. Consequently, the progress over the years of engineering courses at UFBA was studied, based on the concept of Juran (1990).

DEVELOPMENT

Before verifying the evaluation of engineering courses, the IGCs of the two universities compared here were verified. The result is shown in Graph 1, where UFBA's improvement rate between 2017 and 2019 is higher than that of UFRGS. Obviously, it is necessary to consider that, when having higher grades, as is the case at UFRGS, it becomes more difficult to achieve a high rate of improvement.

Graph 1 – UFBA and benchmark improvement rates between 2017 and 2019, measured by the variation of the Continuous IGC of each university.



As explained earlier, quality indicators evaluate Brazilian higher education in a three-year period. The last evaluation that analyzed the engineering courses was in 2019 and so the data processed here are of this year. In addition, some courses are not evaluated by MEC due to pedagogical design and other criteria considered. In 2019, for example, there were no grades for the courses of Surveying and Cartographic Engineering, Mining Engineering and Land Transport Technology in Brazil.

Therefore, the following research will gather data from the other eight Engineering courses of EPUFBA. In addition to these cases, Sanitary and Environmental Engineering, a course that exists at UFBA, was evaluated only as Environmental Engineering. Although there are differences between the focus of these two courses, it is inferable that the data are reliable for an analysis.

In addition, before treating the results of each course, it is important to highlight the functioning of higher education in Brazil and how its characteristics were based on this

research. According to the Ministry of Foreign Affairs, among some classifications, there is the academic-administrative issue. UFBA is a university, a multidisciplinary academic institution that has institutionalized intellectual production, in addition to presenting minimum requirements for an academic master's degree and workload of the faculty. In addition, there are University Centers, Colleges, and Institutes, each with its limitations.
Therefore, with these clarifications, the results analyzed by course will follow, where a course context will be addressed at the Federal University of Bahia (UFBA) followed by the result of the Federal University of Rio Grande do Sul (UFRGS), the previously defined benchmark.

Civil engineering

The Civil Engineering course began from the first years of operation of the Polytechnic School of UFBA. Currently, the profile of the graduate student in this course is generalist, with solid scientific technical training and able to absorb and develop new technologies. Its competencies are diverse, ranging from planning to construction surveys.

In Brazil, according to the CPC (2019), there are 742 civil engineering courses, considering all types of HEIs. Among these, the EPUFBA course is in 156th position, with the Continuous CPC of 3.179 (having 4 as CPC Range).

Making a comparison only between the 275 Universities (excluding university centers, colleges, and institutes), the course is in 86th place. UFRGS, in turn, obtained a score of 3.353 continuous CPC, being in the same range as the Bahian course. In the ranking among universities, the UFRGS course is in 54th position, 32 positions above that of UFBA. Thus, the difference between the course of UFBA and UFRGS is 5.47%

Computer Engineering

In 2019 the Computer Engineering course had 322 active enrollments. The main needs of our market for these engineers are focused on the development of high value-added electronic products. After graduation, this professional will be able to study, design, implement and maintain the conditions required for the operation of installations of electronic computer systems (hardware and software) and other systems.

At UFBA, this course has been offered since 2008. In 2019, the Continuous CPC of this course was 3,888, which led to the great mark of the 5th best course among 178 in the country. Considering only Universities, Computer Engineering of UFBA is in 3rd place in Brazil out of 102 courses. UFRGS, in turn, obtained a score of 3.302, placing 27th

among the country's universities. This shows that the Computer Engineering course at UFBA is 24 positions and 17.75% ahead of the course of Rio Grande do Sul.

Control and Automation Engineering

The Control and Automation Engineering course was implemented at EPUFBA in 2008. The course aims to train professionals capable of designing, maintaining, or developing research on equipment or solutions related to industrial instrumentation, industrial informatics, control, and automation.

In the Continuous CPC assessment, the course obtained a score of 3.139 in 2019, placing in the 51st position of 172 courses examined. Compared to only the 77 universities, it obtained the 32nd highest grade. On the other hand, the UFRGS course received a Continuous CPC score of 3.856, which placed it in the 6th position among the Control and Automation Engineering courses offered by Brazilian universities. Thus, the UFRGS course is 22.84% ahead of the UFBA´s course, with a difference of 26 positions in the *ranking*.

Electrical Engineering

The Electrical Engineering course is one of the oldest of the Polytechnic School of UFBA, having been implemented in 1941. After training, this professional is expected to perform functions such as study, planning and implementation of power systems facilities, telecommunications, and electronic systems. In addition, the graduation comprises engineers with solid scientific and technological preparation, who incorporate creativity in problem solving.

In relation to Continuous CPC, EPUFBA’s Electrical Engineering obtained concept 3.239, leaving the course in the 97th place of 420 HEIs evaluated. Compared only with universities, it reached the 70th place out of 213 courses in Brazil. Meanwhile, UFRGS ranked 46th out of the 213 universities evaluated, with a score of 3.371. This means that UFRGS is 4.07% ahead of the Electrical Engineering course at UFBA, with 24 positions of difference.

Mechanical engineering

Installed at the Polytechnic School of UFBA in 1968, the Mechanical Engineering course aims to train professionals trained to work in the most different areas of industry such as oil, petrochemicals, thermal power plants, hydroelectric and wind, steel mills, breweries, automotive industries etc.

In the last evaluation cycle, the Continuous CPC of this course was 2.963. This score placed this course in 100th place out of 385 courses. Analyzing only universities, it is placed in the 66th position of 174 courses. UFRGS received a score of 3.193, placing 28th among universities. This means that UFBA is 7.76% behind the UFRGS course, which is positioned with 38 different positions above that of UFBA.

Production Engineering

Being one of the most recent courses of the Polytechnic School, started in 2008, the program of the Production Engineering course aims to train students qualified to work in areas such as operational research, production management, reliability, logistics and layout of facilities, also allowing them to have a good complementary humanistic training.

In 2019, the Continuous CPC score obtained was 2.956. In terms of general placement, the UFBA course ranked 220th out of 654 courses. Among the 242 courses of the universities, the UFBA is in 121st place. UFRGS, in turn, ranked 13th among universities, with a score for Continuous CPC of 3.726. This indicates that UFBA is 26.05% away from the UFRGS course, representing 101 positions above.

Chemical engineering

Opened in 1942, the Chemical Engineering course has the mission of training qualified professionals to design and analyze systems, products, and processes; plan, supervise, elaborate, and coordinate engineering projects and services; develop and/or use new tools and techniques; have a socio-environmental vision; design, conduct and analyze experiments.

The score obtained in the Continuous CPC in 2019 was 3.042. This score ranks the UFBA course as the 77th best in Brazil, out of 185 evaluated. The ranking only among universities raises the Bahian course to position 57 of 112 courses. In turn, the UFRGS score was 3.380, which attributed this course to the 22nd position among Brazilian universities. In direct comparison with UFBA, UFRGS is 11.11% ahead with 90 positions in the ranking.

Sanitary and Environmental Engineering

The graduation in Sanitary and Environmental Engineering started at UFBA in 1978. According to the HEI program, the profile of this trained professional is the result of technical, scientific, professional, and humanistic training that aims to enable him to apply and develop technologies, stimulating a critical and creative action in the identification and resolution of problems in the sanitary and environmental spheres.

With the Continuous CPC valued at 3.492, the EPUFBA course is positioned in the 38th place among 292 existing courses. When considering only Brazilian universities, the total becomes 140 and the position of the course of Bahia rises to position 26. On the other hand, the Environmental Engineering course at UFRGS was graded 3.682, reaching the 13th position among Brazilian universities. Thus, the course of UFBA is 13 positions (5.44%) behind the course offered by UFRGS.

RESULTS

The data collection resulted in a broad analysis of the positioning of EPUFBA's engineering courses in relation to the context of Brazil. Table 1 summarizes this information as it gathers the score obtained by each course in the Continuous CPC 2019, the total number of higher education institutions evaluated for each course and the classification of the UFBA in relation to this total.

Table 3 - Relative position of the courses of the Polytechnic School of UFBA, compared to similar courses.

Evaluated Engineering Course	Continuous CPC (2019)	Total HEIs evaluated	Classification
Civil	3.179	742	156th
Computation	3.888	178	5th
Control and Automation	3.139	172	51st
Electric	3.239	420	97th
Mechanics	2.963	385	100th
Production	2.956	654	220th
Chemistry	3.042	185	77th
Sanitary and Environmental	3.492	292	38th

In addition, data collected from UFRGS engineering allowed a direct comparison between the two universities in relation to each of the 8 courses evaluated in the research. As can be seen in Figure 2, UFRGS courses obtained 7 of the 8 courses with Continuous CPC grades higher than that of UFBA. Only Computer Engineering scored higher at UFBA.

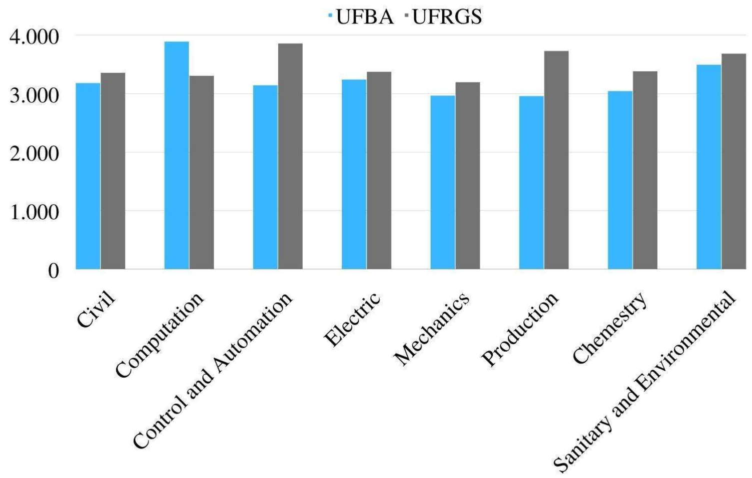


Figure 2 - Continuous CPC of UFBA courses compared to UFRGS courses

From these grades, the percentage of difference between the courses of the two universities was traced, as shown in Table 2. The percentage value is positive when UFBA is ahead and negative when UFBA is behind UFRGS.

Table 4 - Percentage of difference between UFBA and UFRGS engineering

Evaluated Engineering Course	**Continuous CPC (2019) UFBA**	**Continuous CPC (2019) UFRGS**	**Percentage difference UFBA/UFRGS**
Civil	3.179	3.353	-5.47%
Computation	3.888	3.302	+17.75%
Control and Automation	3.139	3.856	-22.84%
Electric	3.239	3.371	-4.07%
Mechanics	2.963	3.193	-7.76%
Production	2.956	3.726	-26.05%

Chemistry	3.042	3.380	-11.11%
Sanitary and Environmental	3.492	3.682	-5.44%
AVERAGE	**3.237**	**3.483**	**- 7.60%**

Based on Table 2, it is possible to notice that the Production Engineering, Control and Automation and Chemistry courses at UFBA are the farthest from the similar course at UFRGS. This means that these should be the courses taken with priority for implementing improvement actions. On the other hand, the Computer Engineering course is 17.75% ahead of the same course offered at UFRGS which indicates good performance of UFBA. From a general perspective, the average continuous CPC of the 8-engineering evaluated by UFBA is 3.159, while for the same courses at UFRGS the average is 3.379. This indicates that, UFBA's engineering courses are 6.96% behind UFRGS courses.

However, comparing the Preliminary Concepts of the Engineering Course of UFBA in 2017 and 2019 (Table 3), it is possible to notice the growth in the performance of six of the eight courses studied. In relation to the averages obtained from the CPC of each year, the result indicates a growth of 8.04% of the grades of the engineering courses of UFBA.

Table 5 - Continuous CPC of UFBA engineering courses in 2017 and 2019

Evaluated Engineering Course	Continuous CPC (2017)	Continuous CPC (2019)	Evolution of the course (%)
Civil	2.945	3.179	+7.95%
Computation	3.065	3.888	+26.85%
Control and Automation	3.152	3.139	-0.41%
Electric	3.220	3.239	+0.59%
Mechanics	2.556	2.963	+15.92%
Production	2.795	2.956	+5.76%
Chemistry	3.163	3.042	-3.98%
Sanitary and Environmental	3.076	3.492	+13.52%

AVERAGE	**2.996**	**3.237**	**+8.04%**

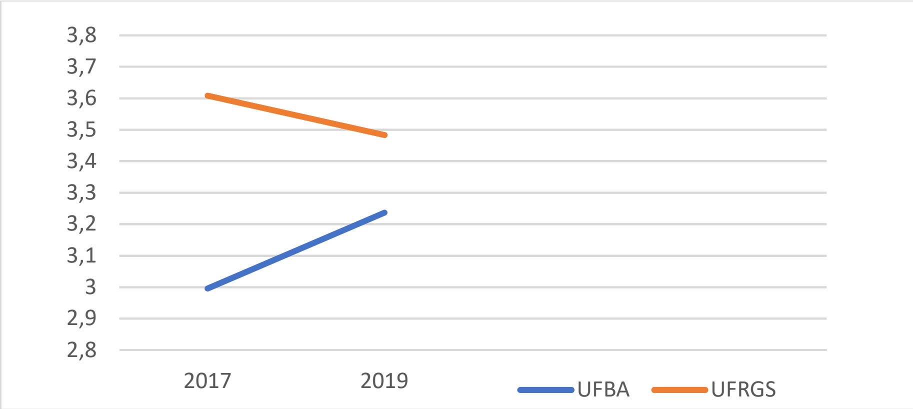
Table 5 shows the evolution of UFRGS courses in the period between 2017 and 2019, with the objective of comparing the improvement rates of the averages of the Continuous CPC found.

Table 6 - Continuous CPC of UFRGS engineering courses in 2017 and 2019

Evaluated Engineering Course	Continuous CPC (2017)	Continuous CPC (2019)	Evolution of the course (%)
Civil	3.244	3.353	+3.36%
Computation	-	3.302	-
Control and Automation	3.702	3.856	+4.16%
Electric	3.369	3.371	+0.05%
Mechanics	3.083	3.193	+3.56%
Production	3.760	3.726	-9.16%
Chemistry	3.681	3.380	-8.91%
Sanitary and Environmental	4.417	3.682	-19.96%
AVERAGE	**3.608**	**3.483**	**-3.59%**

Table 5 indicates the positive evolution of EPUFBA courses over the years, while the opposite result was obtained by UFRGS (Table 6) (Graph 2). On the other hand, as exposed throughout this research, the comparison between the engineering courses of UFBA and the defined benchmark, UFRGS concludes that the courses of the Polytechnic School of Bahia can reach higher levels of national classification if they seek to narrow the gaps between the chosen benchmark and of other HEIs. A visit to UFRGS is planned, an important benchmarking stage to be carried out.
The comparison of the CPC Continuous averages of the eight engineering courses of the two universities is shown in Graph 2.

Graph 2 - UFBA and benchmark improvement rates between 2017 and 2019, measured by the variation in the average of the Continuous CPC of the engineering courses evaluated at each university.



The comparison of the averages of the Continuous CPC (Graph 2) shows more clearly that the evolution of the UFBA courses was greater than that of the benchmark, which is good news, a finding that shows that the process of continuous improvement of the courses at the Polytechnic of UFBA had an effect in this period. According to Juran (1990), the rate of improvement is an important indicator for the development of a company or organization.

Focusing on the ideas of improvements for the courses, which can reflect on better scores for UFBA inside and outside Brazil, suggestions were developed based on the criteria analyzed by the CPC and ENADE. After all, it is assumed that these questions are directly linked to the quality of the courses. The most important items to be improved are:

- Improve the pedagogical organization;
- Have more professors with academic degrees of masters and doctors;
- Make improvements to the School's infrastructure, especially in technical laboratories;
- Offer more postgraduate courses derived from each engineering;
- Review the curriculum of all courses offered.

In addition, it is important to guide students on the importance of carrying out the test and the socioeconomic questionnaire of ENADE. Thus, the university approaches more reliable data on this part of the academic community.

CONCLUSIONS

It was found that the average improvement rate of UFBA courses is higher than the benchmark considered, which is an important finding and validation of the effort being made by EPUFBA's senior management.

But, comparatively, it is possible to notice that the performance of the Federal University of Bahia performs below the level of the benchmark defined for this research, the University of Rio Grande do Sul. According to data presented above, there is a GAP of 7.60% in the general average of the engineering courses evaluated and can reach more than 20% in specific courses.

This data is an indicator of the importance of research and benchmarking for cases of educational institutions, such as this one. After all, the benchmarking methodology is defined as a process that happens from the inside out, that is, internal data are first evaluated that are later compared with external organizations (Ribeiro, 2004).

Therefore, after an analysis of the overview of the eight UFBA engineering courses evaluated it was possible to make suggestions for improvements, which, in summary, refer to the curriculum review (the last one occurred in 2009) from the inclusion of more disciplines with practices**;** general disciplines which address soft skills preparing students to be future professionals and elective disciplines which allow the student to build, his career since graduation. Also, it was pointed out the necessity of investment in infrastructure of rooms and laboratories making them more modern according to technological advances in the market, as well as partnerships with companies that can assist in a better transition from students to professional life.

Thus, by following up on this research, with on-site visits, which are being planned, and a more structured benchmarking, it is desired that the Polytechnic School of UFBA achieve better results in national and international rankings, consequently raising more investments from the Federal Government.

Finally, it should be emphasized that the value of this research, especially in the ideas of improvement, can reflect on larger goods for the community and local interests, since the work that a university the size of UFBA performs impacts people beyond the walls of its School.

ACKNOWLEDGEMENTS

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REFERENCES

Abramowicz, M.; Lara, M. (2010), "Políticas públicas de avaliação: uma pesquisa em currículo", CRV, São Paulo. SP.

Behenck, J. et al (2019), "Utilização de indicadores como apoio de processo de autoavaliação institucional", Universidade Federal do Rio Grande do Sul, Porto Alegre, RS.

BRASIL (1996), Casa Civil, "Lei 9394/1996: Estabelece as diretrizes e bases da educação nacional", Brasília, DF.

BRASIL (2004), Casa Civil, "Lei 10861/2004: Estabelece o Sistema Nacional de Avaliação do Ensino Superior - SINAES", Brasília, DF.

Carvalho, K. A., Sousa, J. C. (2017), "Gestão de Processos: Novo Modelo de Gestão para Instituições Públicas de Ensino Superior". Revista Administração em Diálogo, Vol. 19 No. 2.

INEP (2009), "SINAES – Sistema Nacional de Avaliação da Educação Superior: da concepção à regulamentação", MEC, Brasília, DF.

INEP (2019). "CPC 2019", available at: https://www.gov.br/inep/pt-br/acesso-a-informacao/dados-abertos/indicadores-educacionais/indicadores-de-qualidade-da-educacao-superior (accessed 10 March 2022).

INEP (2019). "IGC 2019", available at: https://www.gov.br/inep/pt-br/acesso-a-informacao/dados-abertos/indicadores-educacionais/indicadores-de-qualidade-da-educacao-superior (accessed 10 march 2022).

INEP (2019). "Conceito Enade 2019", available at: https://www.gov.br/inep/pt-br/acesso-a-informacao/dados-abertos/indicadores-educacionais/indicadores-de-qualidade-da-educacao-superior (accessed 10 March 2022).

INEP (2020), "Nomenclatura Cursos", available at: http://www.dce.mre.gov.br/nomenclatura_cursos.html#:~:text=As%20Instituições%20de%20Ensino%20Superior,não%20cobram%20matrícula%20ou%20mensalidade, (accessed 18 march 2022).

INEP (2020), "Quality Indicators", available at: http://portal.mec.gov.br/component/tags/tag/indicadores, (accessed 15 March 2022).

Jesus, A.R., Dumet, T. B (2019), "Avaliação dos departamentos e melhoria contínua na Escola Politécnica da Universidade Federal da Bahia". 4th Symposium Evaluation of Higher Education, SINAES, Salvador, BA.

Jesus, A.R. *et al*. (2019). “Implementação de Melhoria Contínua na Escola Politécnica”, working paper, 5th International Conference on Lean Six Sigma for Higher Education, Edinburg, UK.

Juran, J. M. (1990), “Juran na liderança pela qualidade – um guia para executivos”. Enio Matheus Guazzelli, São Paulo, SP.

National Quality Foundation (2015). E-book Prático #14 Benchmarking", available at: https://fnq.org.br/comunidade/e-book-14-benchmarking/, (accessed 12 march 2022).

Pires, C., Araújo, D. A. G. (2019), “A avaliação institucional como instrumento de gestão e consolidação do projeto pedagógico institucional na educação superior”, Anais…, 4º Simpósio de Avaliação da Educação Superior, Salvador, BA.

Ribeiro, L. M. M. (2004), “Aplicação do benchmarking na indústria de manufatura: desenvolvimento de uma metodologia para empresas de fundição". Faculdade de Engenharia, Universidade do Porto, Porto, PT.

Silva, E.; Menezes, E. (2005), “Metodologia da pesquisa e elaboração de dissertação”, Universidade Federal de Santa Catarina, Florianópolis, SC.

Stapenhurst, T. (2009), “The Benchmarking Book: A How-to-Guide to Best Practice for Managers and Practitioners”, Elsevier, Oxford, UK.

UFBA, (2020). "Histórico", available at: https://www.ufba.br/historico#:~:text=Universidade%20Federal%20da%20Bahia%20–%20A%20primeira%20do%20Brasil&text=Still%20no%209%20XIX%2C%20incorporated,Sciences%20e%20Letras%20(1941), (accessed 10 April 2022).

EPUFBA (2019), "Politécnica - Histórico", available at: http://www.eng.ufba.br/historia#:~:text=A%20história%20da%20Escola%20Politécnica,o%20final%20do%20século%20XIX. (Accessed 18 March 2022).

EPUFBA (2020), "Relatório de Gestão 2019", available at: http://www.eng.ufba.br/sites/eng.ufba.br/files/relatorio_de_gestao_2019__escola_politecnica.pdf (accessed 20 March 2022).

EPUFBA (2022), "Relatório de Gestão 2021", available at: http://www.eng.ufba.br/sites/eng.ufba.br/files/relatorio_de_gestao_2021.pdf (accessed 20 March 2022).

UFRGS, (2018). “Engenharia - Apresentação”, available at: https://www.ufrgs.br/engenharia/apresentacao/, (accessed 10 April 2022).

UFRGS (2021). “Institucional”, available at: http://www.ufrgs.br/ufrgs/acessoainformacao/institucional, (accessed 10 April 2022).

Yin, R. (2001), “Estudo de Caso: Planejamento e Métodos”, Bookman, Porto Alegre, RS.

Benchmarking Chemical Engineering Courses in Brazil

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STRUCTURED ABSTRACT

Purpose - The objective of this research was to analyze the Chemical Engineering course offered by the Federal University of Bahia (UFBA) through benchmarking with other universities in Brazil, to improve it in the triennial evaluations.

Design/methodology/approach – This is an applied, quantitative, and qualitative research. To develop the benchmarking, comparison parameters were used, such as the Folha de São Paulo University Ranking (RUF), the National Student Performance Exam (ENADE) and the Times Higher Education (THE). A comparison was made between rankings, in addition to a survey of the general course data of UFBA and the selected Institutions. Furthermore, a comparative analysis of the curricula was performed, and a survey was prepared and answered by 28 chemical engineering students. Finally, it was possible to suggest improvements for the course studied.

Findings - The Continuous ENADE Concept of the Chemical Engineering course of UFBA is 25% behind the course of the Federal University of Minas Gerais (UFMG), 18% behind the course of the Federal University of Rio Grande do Sul (UFRGS) and 12% ahead of the course of the Federal University of Rio de Janeiro (UFRJ). Furthermore, the UFBA course presents deficiencies regarding the course updating, including the offering of practical subjects, soft skills and a training of students as a social individual.

Research limitations/implications – There is a lack of visitation to benchmarks, an important step in the benchmarking process, which will be the objective of continuing the research.

Keywords: Benchmarking, Chemical Engineering, Quality, Brazil.

Paper type: Case study

INTRODUCTION

In Brazil, the National High School Exam (Enem) was created in 1998, with the objective of evaluating students' school performance at the end of basic education. From then on, universities, both public and private, began to use this exam in place of the entrance exam, accepting students who have obtained the best grades. This leads the students to choose the best evaluated courses, leaving the others with less qualified students, thus urging universities to seek to improve the evaluation of their courses.

This article is part of a study, the result of the desire of the High Administration of the Polytechnic School of the Federal University of Bahia (EPUFBA) to improve the quality of the 10 engineering courses offered. A survey of the problems was carried out in seven existing departments. More than 500 opportunities for improvement were pointed out. Four Committees were established to monitor the development of the work (Jesus *et al*. 2019) (Jesus and Dumet, 2019). A goal of obtaining a grade 4 in the evaluation carried out by the Federal Government was established and achieved by all courses at the end of 2019.

Now the study consists of comparing the courses with benchmarks - better courses scored nationally, aiming at the process of continuous improvement. The Chemical Engineering course, the focus of this article, is one of the best evaluated at EPUFBA.

It has existed in Brazil since 1942. Professionals in the area brought great contributions to the development of the national industry and growth of the State of Bahia. Universities can graduate students in chemical engineering, and they are required to obtain a license from the Regional Council of Engineering and Agronomy (CREA) to perform the function of engineering in a regulated manner.

The professional in Chemical Engineering acquires competence to perform physical-chemical transformations in various materials, develop technologies to improve processes, build and operate industrial plants. It also develops and supervises the manufacturing processes of products in the industries of the most diverse types of products.

Among the courses available in Brazil, the bachelor's degree offered by the Federal University of Bahia (UFBA) is one of the references at the local level, but may evolve to be one of the best in the country. To study improvements to develop the course, a comparative analysis was made with three other federal universities better positioned in the existing rankings. In possession of the data, it was sought to understand how these institutions apply teaching-learning, seeking solutions to the deficits of the studied course at UFBA.

The search for these solutions was carried out through the application of benchmarking. The Higher Education Institutions (HEIs) selected for the present study were the Federal University of Rio Grande do Sul (UFRGS), the Federal University of Minas Gerais (UFMG) and the Federal University of Rio de Janeiro (UFRJ).

RESEARCH METHODOLOGY

The methodology is a Case Study (Yin, 2001), an Applied Research since it seeks to generate knowledge for practical application and directed to the solution of specific problems. In addition, it is classified as Quantitative Research, because it uses statistical resources and techniques and Qualitative Research because the natural environment is the direct source for data collection. It is also descriptive because the process and its meaning are the main focuses of approach (Silva and Menezes, 2005).

To obtain the benchmarks, the University *Ranking* of Folha de São Paulo (RUF), the National Student Performance Exam (ENADE) and the Times Higher Education (THE) were used. All of them have a robust database, allowing comparisons with notes, positions and other indicators related to public and private education in Brazil.

From these three rankings, the choices for benchmarks were the large universities that stand out at the top of the lists: Universidade Federal do Rio Grande do Sul (UFRGS), Universidade Federal de Minas Gerais (UFMG), and Universidade Federal do Rio de Janeiro (UFRJ). These are public universities of national prominence and, especially, reference in the states that bear their names. After this choice, the performance of UFBA's Chemical Engineering course in each ranking was compared with these three benchmarks.

After collecting the data and comparing performance in the rankings, the research moved towards the internal analysis of each university. In general, the most discussed items were quality of teaching, market evaluation, educational level of teachers and a survey of general data from the UFBA course and the selected institutions. In addition, a comparative analysis of the curriculum of the courses in the different HEIs was carried out.

To complement this last topic, a poll was prepared and answered by chemical engineering students at UFBA. The research was composed mostly of statements, to which students could give a score from 1 to 5, where 1 indicates "Totally Disagree" and 5 represents

"Totally Agree". In this, 28 volunteer students were asked about the quality of the subjects offered in the basic cycle and in the specific cycle. In addition, there were questions about the competence of the curriculum in training professionals capable of performing their functions as engineers and their social training.

Finally, a proposal for an action plan was prepared with suggestions for improvements based on the evaluation criteria of each ranking and the responses of the student volunteers.

LITERATURE REVIEW

In the last decades, the growing debates on institutional evaluation for Higher Education Institutions (HEIs) may be related to the current world as a globalized contemporary society (Silva and Rudá, 2019). This evaluation format became a quality measurement instrument, validating the existence of institutions (Venturini, 2010).

In Brazil, a regulated institutional assessment is regularized by the National Higher Education Assessment System (SINAES), created in 2004. Established by Law 10,861/2004, SINAES regulates the assessment processes in Higher Education Institutions in the country. In its guidelines, there are self-assessment processes, external assessment, National Examination of Student Performance, Assessment of teaching courses, among other aspects. (INEP, 2019).

However, in addition to SINAES, there are other evaluation models used for improvement proposals. On the national scene, for example, there is the Ranking Universitário da Folha (RUF). In the global context, there is the Times Higher Education World Ranking (THE).

According to Encinas (2019), when it comes to federal universities, there is social pressure on improving the quality of teaching, beyond just the number of graduates. Thus, being efficient is a necessity since the frequent scenario is resource constraint. In his work, Encinas (2019) tries to identify promising institutions that serve as a benchmark for the others, promoting learning through the replication of good practices, validating the importance of benchmarking for HEIs

Benchmarking

In any organization, whether for profit or not, one of the main factors influencing success and recognition is the quality standard of the processes they perform or the services and products they offer. In today's globalized world, the growth in the use of technology and the emergence of new methods of data analysis make some entities stand out against the competition. In this scenario, it is increasingly important that organizations have a broad view of the environment they are inserted in, seeking the improvement of internal processes.

One of the main techniques used is benchmarking, which has as its main characteristic the methodical comparison of steps, processes, products, and internal services with those that are performed or offered by organizations that are references in the market. These comparisons are made continuously to analyze the reason for the higher quality and recognition of external processes or products, aiming at increasing internal efficiency.

According to Araújo (2011), benchmarking is defined as

> [...] special modality of learning aimed at revealing the best practices of an organization fully recognized as the number one of its branches [...] in order to provide those who start this type of study in a framework of possibilities for improvement.

The technique in question is not an analysis followed by a simple copy of what has been studied. On the contrary, there needs to be a study in the internal implementation of the solutions developed by other entities, with the keyword being the adaptation. Thus, it is necessary to shape the solutions to the internal parameters, to implement significant improvements.

An attention is required to the terms benchmarking and benchmark. The first was explained just above. The second, benchmark, concerns a lighthouse, which can be quantitative, such as the grade or position in a ranking, or qualitative, as the description of a practice (FNQ, 2015).

UFBA

UFBA, the main University of Estado da Bahia, began in 1808 with the foundation of the Bahia School of Surgery, although the very name of the University occurred only in 1950. During these 214 years of history, the university grew and gained notoriety. Currently, with 3 campuses distributed by the State of Bahia, UFBA has 108 undergraduate courses in 32 teaching units and 42. 300 registered students (PROPLAN, 2021).

The Polytechnic School of the Federal University of Bahia brings together courses related to engineering. It was founded in 1897 and is in Salvador, Bahia, Brazil. Nowadays, it has 10 engineering undergraduate courses, seven academic masters, one professional master's degree, six doctorates, several specialization courses, several extension courses and more than 40 research groups, being the largest unit of UFBA and the largest engineering teaching center in Bahia. The staff consists of approximately 182 permanent teachers and 65 administrative technicians.

UFRGS

The history of UFRGS, based in the city of Porto Alegre, State of Rio Grande do Sul, begins in 1895, with the creation of the School of Pharmacy and Chemistry. With 127 years of existence, the university currently has 4 campuses and 97 undergraduate courses, which had almost 31.000 students in the second semester of 2021 (UFRGS, 2022).

UFRGS´s School of Engineering has approximately 5.000 undergraduate students; about 2.000 *stricto sensu* graduate students and more than 1.500 specialization students. It offers 13 undergraduate courses and 10 postgraduate courses. Its infrastructure consists of 10 teaching laboratories and more than 80 research laboratories spread over 16 buildings. The staff consists of approximately 230 permanent teachers and 130 administrative technicians.

The foundation's history occurred when military engineers, who were professors of the Military College, founded in 1896 the School of Engineering of Porto Alegre. Conceived as an institution for various levels of education, it was the embryo of qualified technical training in Rio Grande do Sul, a concept that is maintained to this day. The School of Engineering, in 1920, was already consolidated as a complex educational organization consisting of eleven Institutes. With elementary, high school, technical and higher education, it internalized the advances of technology, also performing the selection and promotion of talents.

UFMG

UFMG, Federal University of Minas Gerais, was created in 1927, incorporating isolated schools and colleges existing in Belo Horizonte at the time. Currently, it holds about 49,000 students, between undergraduate and graduate, spread over 91 undergraduate courses (UFMG, 2022).

The creation of the School of Engineering of the Federal University of Minas Gerais (EEUFMG), one of the 20 academic units of UFMG, is directly related to the birth of Belo Horizonte, the capital of Minas Gerais, which also brought from the former capital, Ouro Preto, the demand for the creation of educational institutions and through a meeting made to define the academic training of engineers in Minas Gerais as well as in the other Brazilian states. The first Congregation of the Free School of Engineering was founded on May 21, 1911, by 15 founders. EEUFMG has 330 teachers, 160 employees, 8,000 students (undergraduate and graduate), in 13 departments and 11 undergraduate courses in engineering (UFMG, 2022). .

UFRJ

UFRJ was the first university created by the Federal Government of Brazil, in 1920, although some units were already in operation, such as the Polytechnic School, which is considered the seventh oldest engineering school in the world and the first in the Americas. UFRJ currently has 176 undergraduate courses and 232 master's and doctorate courses, which bring together approximately 65,000 students (UFRJ, 2022).

The Polytechnic School of the Federal University of Rio de Janeiro (EPUFRJ) is in the city of Rio de Janeiro, Brazil. Brazilian engineering was born in a military cradle and in 2022 the Polytechnic School completed 230 years of its existence. On 1810, the Prince Regent, future king D. João VI, signed a law creating the Royal Military Academy, which came to succeed and replace the Royal Academy of Artillery, Fortification and Design, and from which descend, in direct line, the Polytechnic School of Rio de Janeiro, later called the National School of Engineering. It then changed to the UFRJ School of Engineering and, today, returning to being the Polytechnic School. EPUFRJ has 190 teachers, 180 employees, more than 4,600 students, in 12 departments and 13 undergraduate engineering courses.

Comparison parameters

ENADE

The National Student Performance Exam (ENADE) is one of the main drivers of the teaching quality of Brazilian HEI (Higher Educational Institutions). The exam in question evaluates the performance of undergraduate students, considering the programmatic contents provided for in the curriculum guidelines of the courses, in addition to the development of skills and competencies related to the graduation in question. Enade has been applied since 2004 by the National Institute of Educational Studies and Research Anísio Teixeira (INEP) and, together with other parameters, serves to evaluate the overall performance of universities in relation to the courses offered.

The main highlight of Enade is the ability to perform a comparative analysis of HEIs over time, internally, and externally. The areas of knowledge for bachelor's and bachelor's degrees derive from the table of areas of knowledge published by the National Council for Scientific and Technological Development (CNPq). The technological axes are based on the National Catalog of Higher Technology Courses (CNCST) of the Ministry of Education (MEC).

RUF

Like Enade, the University Ranking of Folha (RUF) is also used for comparative analysis among Brazilian universities, especially among the quality of undergraduate courses. The RUF is an annual evaluation of active universities that uses national and international data, as well as two opinion surveys of Datafolha, the research and informatics sector that is part of the well-known newspaper Folha de São Paulo (DATAFOLHA, 2021). This ranking evaluates five aspects: research, teaching, market, internationalization, and innovation. Each aspect has different components, totaling eighteen of them. The percentage of contribution of the five aspects is proportional to the quantity and importance of the components that form them.

THE

The Times Higher Education World University Rankings (THE), as the name suggests, is one of the international rankings of universities, being one of the most respected in the world, along with the QS Ranking and the Academic Ranking of World Universities. THE has the possibility of a benchmarking analysis involving internationally recognized universities. In addition, one can separate the ranking by continent, subcontinent, or country, which can facilitate or specify the search.

RESULTS

RUF

According to the RUF, between 2016 and 2019, UFBA (Table 1) was among the 14th and 15th positions among the best Brazilian universities. The other HEIs taken as benchmarks remain among the TOP 5. Moreover, one of the prominent factors about the ranking is that, over time, there is little variation in the positions of the universities in question. This may show that, considering the aspects and components of the RUF that were mentioned above, Brazilian universities have difficulties in introducing processes and making innovations that significantly impact the general position in relation to others. This characteristic may indicate that HEIs are progressing continuously and simultaneously.

A separate case is UFRJ, which, over the period analyzed, showed a progressive decline in the positions occupied in the RUF. Despite this, in 2019, the university was in 3rd place and can be considered as a reference for research.

Table 1 - Position in the Ranking of Best Universities according to RUF

University	**2016**	**2017**	**2018**	**2019**
UFRJ	1st	1st	2nd	3rd
UFRGS	5th	5th	5th	5th
UFMG	4th	4th	3rd	4th
UFBA	14th	15th	14th	14th

In addition to the quality of education (Table 2), the UFBA had an improvement from 22nd to 19th between 2016 and 2019, which is a positive factor. In turn, UFMG has a stable history in 1st place and UFRJ and UFRGS among the five best in Brazil.

It is noteworthy that the advance of 3 positions by UFBA in the ranking of teaching quality, compared to the constancy or fall of other universities, does not necessarily mean that UFBA performed better over time compared to the others. This is because it is a positional ranking and not a crude analysis of the scores obtained in each Criterion of the RUF. Thus, the jump of 3 positions may signal an increase in the quality of teaching, as well as indicate a reduction in the teaching quality of the most direct "competitors" of UFBA. In short, it cannot be said that there has been an absolute increase in quality, only a relative increase.

Table 2 - Ranking by Quality of Teaching according to RUF

University	**2016**	**2017**	**2018**	**2019**
UFRJ	3rd	2nd	3rd	4th
UFRGS	4th	4th	2nd	3rd

UFMG	1st	1st	1st	1st
UFBA	22nd	21st	18th	19th

Finally, Table 3 shows the position over time in relation to the bachelor's degree in chemical engineering in the HEIs analyzed. This course of UFBA had a fall, moving from the position of 12th in 2016 to the 16th position in 2019. Analyzing Table 3, we noticed a significant difference from the other HEIs in relation to it.

The significant decrease in the position of the course at UFBA is not in agreement with the supposed increase in the quality of teaching, evidenced in Table 2. This fact is credible in the discussion presented above, which draws attention to the fact that the increase in position in the ranking does not necessarily indicate an absolute improvement in the quality of teaching, especially in relation to a specific course.

Table 3 - Ranking of the Undergraduate Course of Chemical Engineering according to RUF

University	2016	2017	2018	2019
UFRJ	3rd	3rd	3rd	4th
UFRGS	5th	5th	6th	6th
UFMG	4th	4th	4th	3rd
UFBA	12th	12th	12th	16th

ENADE

The ENADE Concept is a quality indicator that evaluates the courses through the students' performances. This is a parameter widely used when it comes to comparisons, in the same year, between different universities in Brazil. The ENADE Concept can be defined continuously, in decimal numbers ranging from 0 to 5, or to make the visualization of the banknotes clearer, ranging from 1 to 5 considering only the integer numbers. There are also the Preliminary Course Concept (PCC) and the Continuous Preliminary Course Concept (Continuous PCC). The term "preliminary" is used because in some cases a committee visits the University to establish a "definitive" concept of the course. As seen in Table 4, UFMG and UFRGS have the higher score, while UFBA and UFRJ have a grade 4 concept. Over the three years – 2014, 2017 and 2019, the Enade concept for the HEIs studied was constant. It is worth noting that Enade evaluates the courses every three years, but in 2019 there was an exception; instead of the evaluation taking place in 2020, it occurred in 2019.

Analyzing only 2019, and considering the Continuous Enade Concept, it is possible to compare the relationship between the performance of students at these universities in a more reliable way.

Table 4 - ENADE University Concept: CPC and Continuous CPC

University	Continuous ENADE (PCC)	ENADE (PCC)
UFBA	3,559	4
UFMG	4,447	5
UFRGS	4,190	5
UFRJ	3,184	4

In terms of the position among the four universities analyzed here, UFBA is in 3rd place, being 25% behind the course of UFMG, 18% behind the UFRGS course and 12% ahead of the Chemical Engineering course at UFRJ.

Because the Enade Concept (PCC) established in track is a general classification of grades, getting the same value does not mean that both faculties are at the same level of quality. This is clear in relation to UFRJ and UFBA that have a score of 4, but the UFBA stands out when analyzing the continuous value (Table 4).

THE

Table 5 - THE Ranking of Latin America 2021

University	Placement
UFMG	4th

UFRGS	5^{th}
UFRJ	8^{th}
UFBA	26^{th}

As stated earlier, THE encompasses an international ranking of universities. For the work in question, a regional analysis was preferred, considering the position of the HEIs in Latin America. The results obtained for the year 2021 (Table 5), show a significant discrepancy between UFBA and the other universities in question. UFMG, UFRGS, and UFRJ are among the top eight universities in Latin America, while UFBA occupies the 26^{th} position.

Although it is an international comparison, and factors such as internal policy of countries, education and quality of life can influence placement, the great distance between UFBA and the three Brazilian universities used in this comparison is able to show in a more impactful way the difference in the quality of teaching that was presented in Enade and RUF. It is noteworthy that these classifications are not specific to the Chemical Engineering course but serve as a great beacon to perform benchmarking with a broader and more assertive view.

In 2022, 1188 universities were evaluated and, from the 100th position in the ranking, they are grouped by range. THE World University Ranking also assesses courses such as general engineering, chemical engineering, electrical and electronic engineering, civil engineering, and mechanical and aerospace engineering. In this year, considering chemical engineering, all 4 universities studied had their performance evaluated, according to Table 6. UFRGS and UFRJ had the best positions, followed by UFMG and UFBA, respectively.

Table 6 - THE World Ranking of chemical engineering 2022

University	Placement	Overall
UFMG	801 - 1000	17.1 - 27.6
UFRGS	601 - 800	23.7 - 29.8
UFRJ	601 - 800	23.7 - 29.8

UFBA	1001+	8.8 - 17

Curriculum

The curriculum is of fundamental importance for the students' education. The subjects studied must have a connection with the *status quo* and present the main hard skills, as well as the soft skills that the engineer needs to meet the job market.

The curricula, which appear in the annex, show that the basic cycles are very similar, but UFBA has a leaner curriculum compared to other HEIs, with fewer subjects focused on mathematics and logical reasoning.

In the specific cycle, it was noticed that UFBA has a robust curriculum and a lot of materials together with UFRGS. UFRJ has a curriculum that is much more focused on specific subjects and UFMG has more subjects outside the chemical environment, such as Introduction to Sociology and Portuguese Language Workshop. This can be a very positive point, as the university has a role in social transformation. Training human beings with non-standard thinking contributes to professional, social and, above all, personal growth.

UFBA has a workload of 4,029 hours, UFRGS of 4,025 hours, UFMG of 3,750 hours, UFRJ of 3,600 hours, which shows that having a high amount of course hours does not necessarily increase the performance of the course. UFRJ has the lowest workload and is constantly one of the best universities in the country.

Thus, it was perceived that the curricular grid is a significant point of improvement for the course at UFBA, which may represent a great advance in the indicators in the medium term. The curriculum is from 2008, and with the continuous and rapid changes in technology and the job market, a reanalysis of it can improve the course's performance.

Survey

To complement the analysis of the curriculum of the studied course, a survey was prepared among the UFBA' s students. They were asked about the quality of the subjects offered in the basic cycle and in the specific cycle. In addition, there were questions about the competence of the curriculum in training professionals capable of performing their functions as engineers and their social training. Finally, it was requested, optionally, that the students suggest improvements to the points of displeasure. Below are the most interesting results.

Regarding the period, 63% of the interviewees are between the 5th and 7th semesters, while 37% are between the 1st and 4th semesters. The research was composed mostly of statements, to which students could give a score from 1 to 5, where 1 indicates "Totally Disagree" and 5 represents "Totally Agree".

The first statement (Figure 1) concerns the adequacy of the basic cycle of chemical engineering. In this question, 74% of the interviewees answered that they consider the basic cycle completely or partially adequate, as indicated in Figure 1. This result indicates that, although the UFBA contains fewer basic subjects related to logical reasoning and mathematics, the students consider it appropriate for the course.

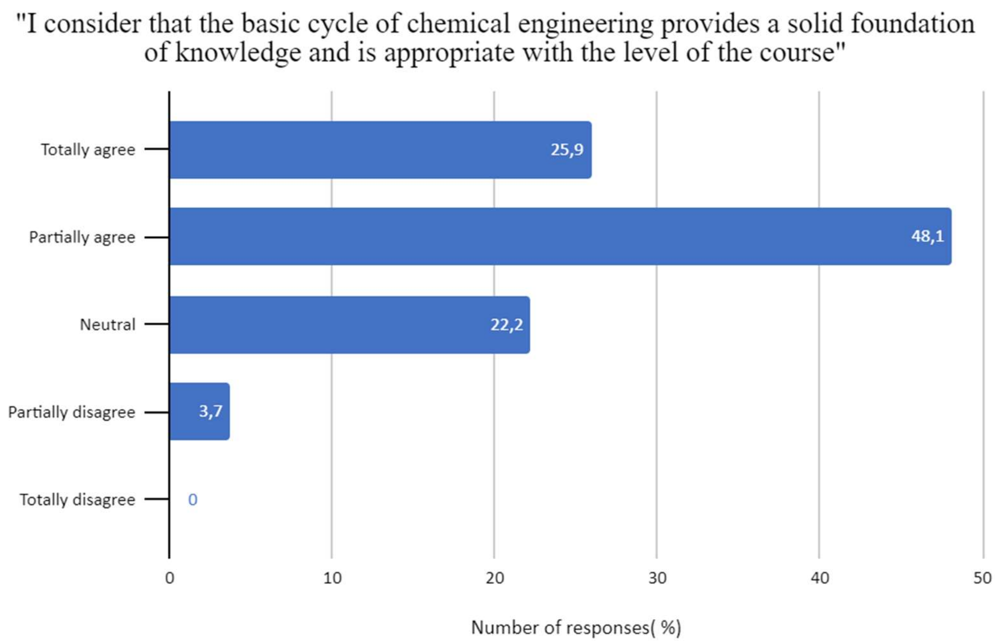

Figure 1 - Question 1: answers about the basic cycle

Another encouraging result was in relation to the hard skills required for a chemical engineer (Figure 2). For this topic, 55.5% answered that they agree totally or partially with the statement that the course offered by UFBA can offer most of the hard skills to the students.

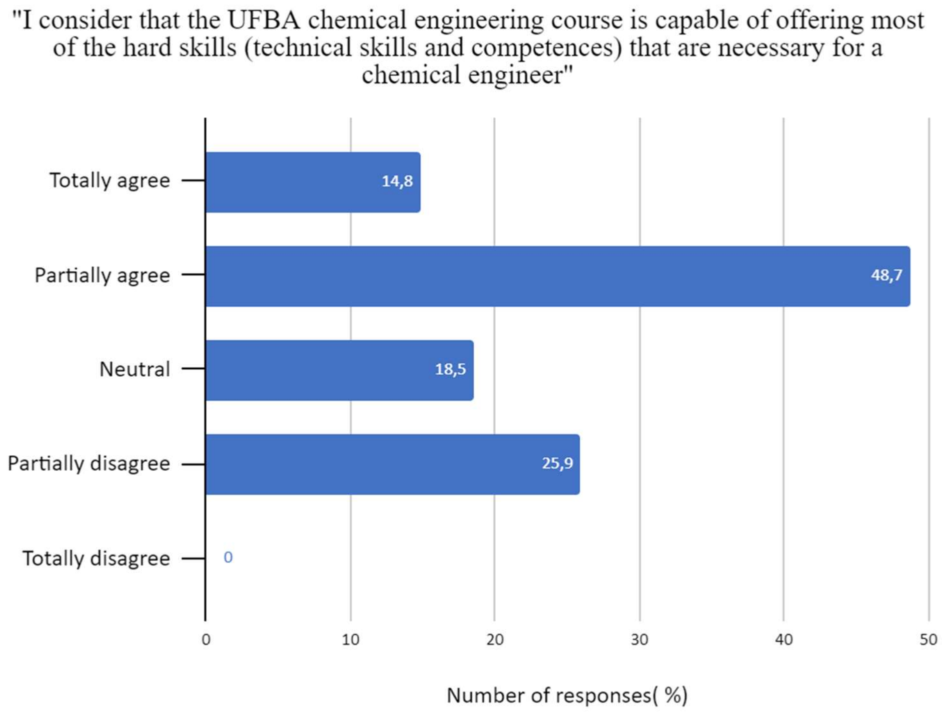

Figure 2 - Question 2: answers about hard skills

Responses play a more pessimistic role when broader issues are dealt with for the training of citizens. The first of these points concerns the training of the engineer as a social individual. It is known that nowadays, soft skills such as teamwork, leadership, communication, resilience, and flexibility are extremely sought after in the labor market, not being different for engineers. Thus, a statement was introduced in the research that used the competence of UFBA to train humanized and integrated professionals in society. Figure 3 shows that 55.5% of the answers disagree totally or partially with the statement and 18.5% are neutral, totaling 74% of answers that do not agree with the proposed statement. This may reflect the small number of subjects outside the scope of the exact sciences that are mandatory in the UFBA curriculum. It was also pointed out by the students that there are several subjects in human sciences offered as optional that, however, in the face of other optional engineering subjects, are left as a second option.

For UFMG, 65% of the interviewees answered that they fully or partially agree. At UFRJ, the percentage was 58.3%. Finally, at UFRGS, the percentage of agreement was 68%. The course of UFBA, with 26%, presents an important gap in this aspect, which is an important finding.

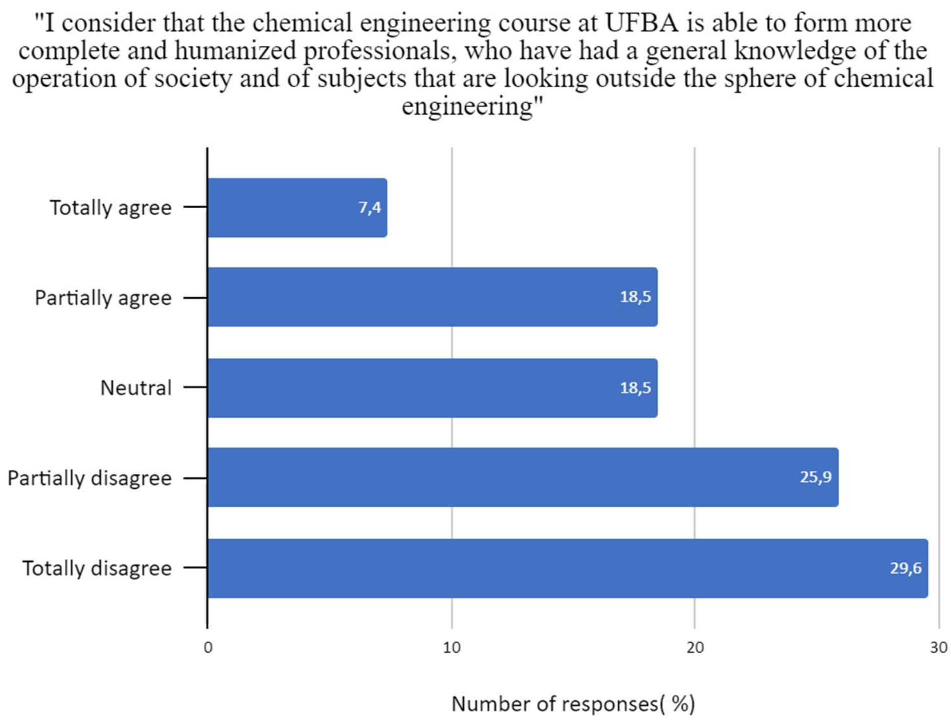

Figure 3 - Question 3: Answers about training as a social individual

Another not encouraging result is related to the updating of the course in relation to skills needed by professionals (Figure 4). 92.5% of the students did not agree, and 81.4% disagreed totally or partially. This scenario is very worrisome and may reflect the old curricular grid, since the last update was performed in 2008.

The students also mentioned the existence of disciplines considered unnecessary for the chemical engineer's performance, outdated learning methods and high workload as problems related to this last statement. It was also scored about the tools used in the area, such as Excel, Power BI, Python programming, which are approached superficially or nulls. In addition, they also asked about the role of the engineer as a communicator and the importance of developing soft skills.

Finally, they point out that the Collegiate has a very large focus on the research area and little market view, which is also an important finding. The Chemical Engineering course created the first Graduate Program in the Polytechnical School, which is a positive differential of the same, although it may be relegating the focus also on the labor market.

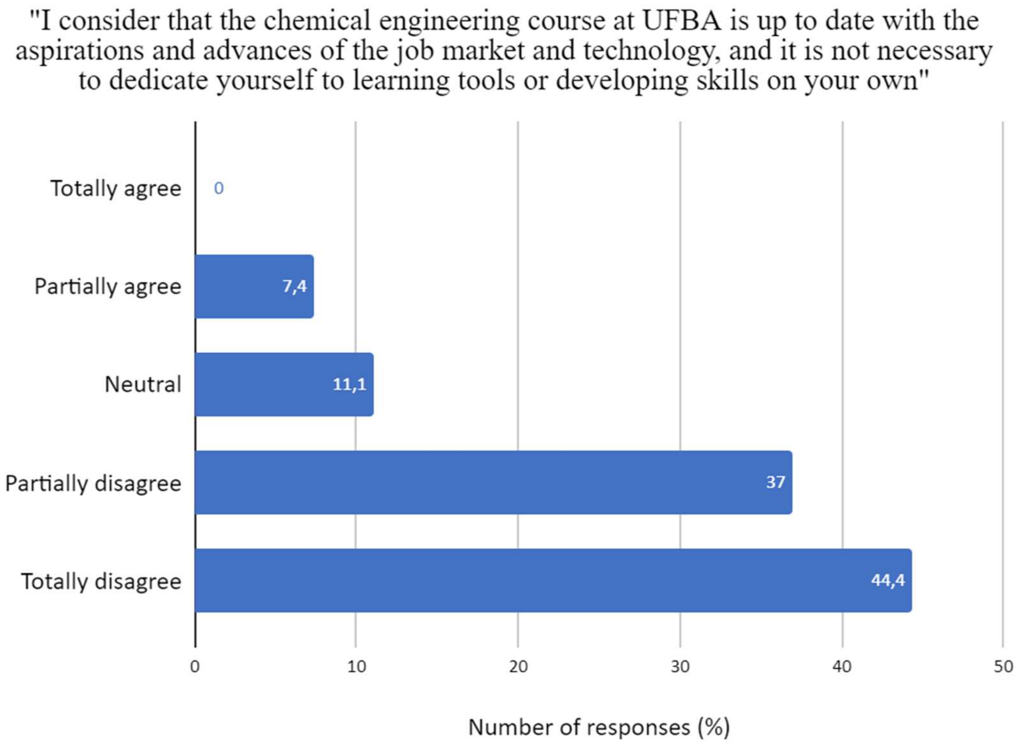

Figure 4 - Question 4: Answers about course update

As for the statement that the course was able to provide practical knowledge beyond the classroom, 37% were neutral, while 29.6% partially agreed and 25.9% partially disagreed, characterizing a technical tie. Finally, when asked about complementary activities, 81.5% consider them attractive and important in professional training.

SUGGESTED IMPROVEMENTS - ACTION PLAN

Taking into account the analysis addressed in the previous sections, an action plan was developed to propose improvements to the studied course in order to bring it closer to the courses used as benchmarks. To this end, the 5W1H tool was used, aiming to propose more detailed and specific solutions to the problems reported in the questionnaires, especially regarding the questions about the technological adaptation of the course and its current capacity to train humanized professionals. The proposals were also based on the evaluation criteria of the above mentioned rankings, ENADE, RUF and THE, as well as on the comparison between the UFBA curriculum and the reference values. Below are the proposals for intervention.

Proposal 1

- What - Update the curriculum of Chemical Engineering;
- Who - Collegiate /Department of Chemical Engineering of UFBA;
- When - In 2022/2023
- Why - To make the grid more up to date with advances in the labor market and to reduce the extra workload of undergraduate students;
- How - Performing an analysis of the current grid to remove or modify disciplines that are important to the chemical engineer. In addition, conduct polls and roundtables with undergraduate students to understand their longings.

Proposal 2

- What - Add compulsory disciplines of the humanities;
- Who - Collegiate /Department of Chemical Engineering of UFBA;
- When - In 2022/2023;
- Why - Improve the training of students as social individuals;
- How - Performing an analysis of the current grid to remove or modify disciplines that are important for the formation and understanding of society.

Proposal 3

- What - Introduce more up to date teaching and evaluation methods;
- Who - Professors/Collegiate/Department of Chemical Engineering at UFBA;
- When - 2022/2023;
- Why - Make the living room environment a place that stimulates learning and encourages students;
- How - Conducting a study of different teaching and evaluation techniques that have better results than the classic ones and applying them.

Proposal 4

- What - Carry out more practical activities;
- Who - Professors/Collegiate/Department of Chemical Engineering at UFBA;
- When - Constantly;
- Why - Making training more practical can help students to stand out in the labor market and understand subjects more deeply;
- How - Conducting real case studies, technical visits, laboratory tests, among others.

Proposal 5

- What - Offer courses related to the most used tools in the market;
- Who - Collegiate /Department of Chemical Engineering of UFBA;
- When - Constantly;
- Why - Stimulating the equity of knowledge of engineering tools helps to train better professionals;
- How - Preparing workshops, lectures, and courses on subjects such as Power BI, Excel, programming in current languages, among others.

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CONCLUSIONS

Through the benchmarking technique a comparison was made with other higher education institutions. The research provided the identification of the main points that serve as assistance for the UFBA to develop the Chemical Engineering course, demonstrating it to be an important tool for quality management.

The present research identified the need to apply improvements that aim to leverage the performance of the Chemical Engineering course at the Federal University of Bahia such as: updating the curriculum, adding compulsory subjects in the humanities, introducing more up-to-date teaching and assessment methods, performing more practical activities, and offering courses related to the most commonly used tools in the market.

In short, the goal was reached, making it noticeable that some changes need to be implemented as shown in the action plan, showing that the study is important for the creation of possible solutions.

REFERENCES

ARAÚJO, L. (2011), Organização, Sistemas e Métodos e as Tecnologias de Gestão Organizacional: Arquitetura organizacional, *benchmarking*, *empowerment*, gestão pela qualidade total, reengenharia. São Paulo: Atlas, SP.

Datafolha (2021), "Datafolha - História", available at: https://datafolha.folha.uol.com.br/sobre/historia/index.shtml (accessed 15 September 2021).

Folha de São Paulo (2019), "Ranking Universitário da Folha de São Paulo", available at: https://ruf.folha.uol.com.br/2019/ranking-de-universidades/principal/, (accessed 3 September 2021).

Encinas, R. (2019), "Avaliação de políticas públicas: eficiência das universidades federais e identificação de benchmarks por meio de análise envoltória de dados", working paper, Universidade Federal Tecnológica do Paraná, Paraná, september 02.

Times Higher Education (2022), "World University Rankings 2022 subject: engineering", available at https://www.timeshighereducation.com/world-university-rankings/2022/subject-ranking/engineering#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/stats (accessed 16 may 2022).

INEP (2019). "Conceito ENADE", available at: https://www.gov.br/inep/pt-br/areas-de actuacao/pesquisas-estatisticas-e-indicadores/indicadores-de-qualidade-daeducacaosuperior/conceitoenade#:~:text=O%20Conceito%20Enade%20%C3%A9%20um,estudantes%20conclunte s%20participantes%20%20exame (accessed 10 September 2021).

Jesus, A. et al (2019). "Implementação da Melhoria Contínua na Escola Politécnica da Universidade Federal da Bahia", working paper, 5th International Conference on Lean Six Sigma for Higher Education, Edinburg. 25 June.

Jesus, A., Dumêt, T. (2019). "Avaliação dos departamentos e melhoria contínua na Escola Politécnica da Universidade Federal da Bahia". 4th Symposium Evaluation of Higher Education. SINAES, Salvador.

National Quality Foundation (2005). "Practical E-book #14 Benchmarking", available at: https://fnq.org.br/comunidade/e-book-14-benchmarking/ (accessed 20 September 2021).

Silva, E.; Menezes, E. (2005), "Metodologia da pesquisa e elaboração de dissertação", working paper, Universidade Federal de Santa Catarina, Florianópolis, SC.

Silva, G. Rudá, C. (2019), "Análise das métricas de qualidade do ensino nos rankings", Universidade Federal do Sul da Bahia, Bahia.

SIQUEIRA, D. (2018). "Benchmarking Interno:Uma ferramenta de gestão para melhoria contínua ao processo educacional", available at: https://fapan.edu.br/wp-content/uploads/sites/14/2018/04/ed3/1.pdf (accessed 3 September 2021).

Times Higher Education (2021) "Latin America University Rankings", available at: https://www.timeshighereducation.com/world-university-rankings/2016/latin-ameri ca university-rankings#!/page/0/length/25/sort_by/rank/sort_order/asc/cols/undefine (accessed 10 September 2021).

UFBA (2021), "Curso de Engenharia Química", available at: http://www.eng.ufba.br/curso graduation/engineering-chemistry (accessed 10 September 2021).

UFMG (2021), "Curso de Engenharia Química", available at: https://ufmg.br/cursos/graduacao/2409/90326 (accessed 10 September 2021).

UFRGS (2021), "Curso de Engenharia Química", available at: http://www.ufrgs.br/ufrgs/ensino/graduacao/cursos/exibeCurso?cod_curso=326 (accessed 10 September 2021).

UFRJ (2021), "Curso de Engenharia Química", available at: http://www.eq.ufrj.br/graduacao/cursos/engenharia-quimica/ (accessed 10 september 2021).

Venturini, J.C. et al (2010), "Percepção da avaliação: um retrato da gestão pública em uma instituição de ensino superior (IES)", Revista de Administração Pública, Vol. 44 No. 1, pp. 31-53.

Yin, R. (2001), "Estudo de Caso: Planejamento e Métodos", Bookman, Porto Alegre, RS.

ATTACHMENT

Curriculum of the Chemical Engineering course of the HEIs analyzed.

UFBA

SEMESTRE 1
ENGC99 INTRODUÇÃO À ENGENHARIA QUÌMICA
MATA01 GEOMETRIA ANALÍTICA
MATA02 CÁLCULO A
QUI037 QUÍMICA GERAL

SEMESTRE 2
ENGD01 MÉTODOS COMPUTACIONAIS NA ENGENHARIA
FIS121 FISICA GERAL E EXPERIMENTAL I-E
MATA03 CÁLCULO B
MATA07 ÁLGEBRA LINEAR A
QUIA14 QUÍMICA INORGÂNICA BÁSICA I

SEMESTRE 3
ENGD02 ESTATÍSTICA NA ENGENHARIA
FIS122 FISICA GERAL E EXPERIMENTAL II-E
MATA04 CÁLCULO C
QUIA01 PRINCÍPIOS DA ANÁLISE QUÍMICA
QUIA15 FÍSICO QUÍMICA -A

SEMESTRE 4
ENG372 PROCESSOS UNITÁRIOS DA INDÚSTRIA QUÍMICA
ENGD04 MÉTODOS MATEMÁTICOS E COMPUTACIONAIS NA
FIS123 FISICA GERAL E EXPERIMENTAL III-E
QUI138 QUIMICA ORGANICA FUNDAMENTAL III
QUIA16 FÍSICO QUÍMICA- C
QUIA17 QUÍMICA ORGÂNICA PRÁTICA

SEMESTRE 5
ENG008 FENOMENOS DE TRANSPORTE I-A
ENG269 CIÊNCIAS DO AMBIENTE
ENG353 CALCULO DE REATORES
ENG396 TERMODINAMICA I
ENGD05 MECÂNICA DOS SÓLIDOS APLICADA A PLANTAS IN
QUI139 QUIMICA ORGANICA FUNDAMENTAL IV

SEMESTRE 6
ENG003 ELETRICIDADE
ENG358 FENOMENOS DE TRANSPORTE II
ENG426 OPERACOES UNITARIAS DA INDUSTRIA QUIMICA
ENG427 TERMODINAMICA II
OPT068 OPTATIVA 068
OPT068 OPTATIVA 068

SEMESTRE 7
ENG009 CONTROLE DE PROCESSOS QUÍMICOS
ENG185 OPERACOES UNITARIAS DA INDUSTRIA QUIMICA II
ENG364 PRODUCAO E TRANSPORTE DE CALOR
ENG421 FENOMENOS DE TRANSPORTE III
ENGD06 ENGENHARIA ECONÔMICA E GESTÃO
OPT068 OPTATIVA 068

SEMESTRE 8
ENG360 MATERIAIS DE CONSTRUCAO E QUIPAMENTOS
ENGD03 LABORATÓRIO DE ENGENHARIA QUÍMICA
ENGD08 TRABALHO FINAL DE CURSO NA ENGENHARIA OU
OPT068 OPTATIVA 068

SEMESTRE 9
ENG363 PROJETO E PLANEJAMENTO DA INDÚSTRIA QUÍMIC
ENGD07 OPERAÇÃO E SEGURANÇA DE PLANTAS INDUSTRI
OPT068 OPTATIVA 068

SEMESTRE 10
ENG369 ESTÁGIO INDUSTRIAL EM ENGENHARIA QUIMICA

Total de Carga Horária: 4029

UFMG

SEMESTRE 1
DCC001-DIG - PROGRAMACAO DE COMPUTADORES
EQM009-DIG - INTRODUCAO A ENGENHARIA QUIMICA
FIS151-DIG - FÍSICA EXPERIMENTAL BÁSICA: MECÂNICA
MAT001-DIG - CALCULO DIFERENCIAL E INTEGRAL I
MAT038-DIG - GEOMETRIA ANALITICA E ALGEBRA LINEAR
QUI003-DIG - QUIMICA GERAL B
QUI019-DIG - QUIMICA GERAL EXPERIMENTAL

SEMESTRE 2
DCC034-DIG - CALCULO NUMERICO
EST031-DIG - ESTATISTICA E PROBABILIDADES
FIS065-DIG - FUNDAMENTOS DE MECANICA
MAT039-DIG - CALCULO DIFERENCIAL E INTEGRAL II
QUI601-DIG - QUIMICA INORGANICA I

SEMESTRE 3
FIS069-DIG - FUNDAMENTOS DE ELETROMAGNETISMO
MAT002-DIG - CALCULO DIFERENCIAL E INTEGRAL III
MAT015-DIG - EQUACOES DIFERENCIAIS A
QUI602-DIG - FISICO-QUIMICA I
QUI603-DIG - QUIMICA ORGANICA I
SOA138-DIG - INTRODUCAO A SOCIOLOGIA

SEMESTRE 4
FIS153-DIG - FÍSICA EXPERIMENTAL BÁSICA: ELETROMAGNETISM
MAT016-DIG - EQUACOES DIFERENCIAIS B
QUI604-DIG - FISICO-QUIMICA II
QUI605-DIG - QUIMICA ORGANICA II
QUI606-DIG - QUIMICA ANALITICA I

SEMESTRE 5
ELE012-DIG - ELETROTECNICA GERAL C
EQM013-DIG - ANALISE INSTRUMENTAL
EQM051-DIG - FENOMENOS DE TRANSPORTE I
EQM052-DIG - QUIMICA DE PROCESSOS
EQM053-DIG - TERMODINAMICA FISICA

SEMESTRE 6
ECN075-DIG - ECONOMIA PARA ENGENHARIA
EQM031-DIG - TERMODINAMICA QUIMICA
EQM035-DIG - FENOMENOS DE TRANSPORTE II
EQM057-DIG - CIENCIAS DOS MATERIAIS
EQM077-DIG - PLANEJAMENTO E ANÁLISE DE EXPERIMENTOS

SEMESTRE 7
EPD001-DIG - ORGANIZACAO INDUSTRIAL PARA ENGENHARIA
EQM034-DIG - DESENHO TECNICO F
EQM036-DIG - TRANSFERENCIA DE MASSA
EQM043-DIG - OPERACOES UNITARIAS A
EQM055-DIG - CINETICA E CALCULO DE REATORES I
EQM129-DIG - ENGENHARIA DE CORROSAO

SEMESTRE 8
EQM039-DIG - CINETICA E CALCULO DE REATORES II
EQM040-DIG - OPERACOES UNITARIAS B
EQM054-DIG - LABORATORIA DE FENOMENOS E OPERACOES
EQM056-DIG - PROCESSOS INDUSTRIAIS I
UNI003-DIG - OFICINA DE LINGUA PORTUGUESA: LEITURA E PROD

SEMESTRE 9
EQM041-DIG - LABORATORIO DE OPERACOES E PROCESSOS
EQM042-DIG - OTIMIZACAO E ANALISE DE PROCESSOS
EQM049-DIG - PROJETO DE PROCESSOS

SEMESTRE 10
DIT001-DIG - DIREITO E LEGISLACAO
EQM050-DIG - AVALIACAO ECONOMICA DE PROJETOS
EQM058-DIG - PROCESSOS PARA PROTECAO AMBIENTAL
EQM059-DIG - INSTRUMENTACAO E ENGENHARIA DE CONTROLE I
EQM063-DIG - ESTAGIO SUPERVISIONADO

Total de Carga Horária: 3750

UFRGS
SEMESTRE 1
CÁLCULO E GEOMETRIA ANALÍTICA I - A
FÍSICA I-C
INTRODUÇÃO A ENGENHARIA QUÍMICA
QUÍMICA GERAL EXPERIMENTAL
QUÍMICA GERAL TEÓRICA
SEMESTRE 2
ÁLGEBRA LINEAR I - A
CÁLCULO E GEOMETRIA ANALÍTICA II - A
DESENHO TÉCNICO I-A
FÍSICA III
QUÍMICA INORGÂNICA PARA ENGENHEIROS B
SEMESTRE 3
EQUAÇÕES DIFERENCIAIS II
FÍSICA GERAL - ELETROMAGNETISMO
FÍSICO-QUÍMICA I - B
GEOMETRIA DESCRITIVA II-A
INTRODUÇÃO À PROGRAMAÇÃO
INTRODUÇÃO AOS PROCESSOS DA INDÚSTRIA QUÍMICA
QUÍMICA ORGÂNICA I - B
SEMESTRE 4
FÍSICA IV - D
FÍSICO-QUÍMICA II - B
MATEMÁTICA APLICADA II
QUÍMICA ANALÍTICA INSTRUMENTAL APLICADA -A
QUÍMICA ORGÂNICA II - B
TRANSFERÊNCIA DE CALOR E MASSA I
SEMESTRE 5
CÁLCULO NUMÉRICO
ESPECTROSCOPIA ORGÂNICA
FÍSICO-QUÍMICA EXPERIMENTAL
MECÂNICA
TERMODINÂMICA PARA ENGENHARIA QUÍMICA
TRANSFERÊNCIA DE QUANTIDADE DE MOVIMENTO
SEMESTRE 6
ELETRICIDADE D
MECÂNICA DOS FLUIDOS APLICADA
OPERAÇÕES UNITÁRIAS DA ENGENHARIA QUÍMICA I
PROBABILIDADE E ESTATÍSTICA
QUÍMICA ORGÂNICA EXPERIMENTAL I-A
RESISTÊNCIA DOS MATERIAIS A
TRANSFERÊNCIA DE CALOR E MASSA II
SEMESTRE 7
CÁLCULO DE REATORES QUÍMICOS
CIÊNCIA DOS MATERIAIS - D
DESENHO TÉCNICO II-A
ENGENHARIA AMBIENTAL
OPERAÇÕES UNITÁRIAS DA ENGENHARIA QUÍMICA II
ENGENHARIA DE REATORES NUCLEARES
SEMESTRE 8
APLICAÇÕES INDUSTRIAIS DO CALOR
BIOENGENHARIA - B
CÁLCULO DE REATORES QUÍMICOS HETEROGÊNEOS
CONTROLE DE PROCESSOS INDUSTRIAIS
LABORATÓRIO DE ENGENHARIA QUÍMICA
OPERAÇÕES UNITÁRIAS DA ENGENHARIA QUÍMICA III - A
SEMESTRE 9
ADMINISTRAÇÃO E FINANÇAS
INSTRUMENTAÇÃO DE PROCESSOS INDUSTRIAIS
METODOLOGIA DO TRABALHO CIENTÍFICO - ENGENHARIA QUÍMICA
MODELAGEM, SIMULAÇÃO E OTIMIZAÇÃO DE PROCESSOS
PLANEJAMENTO E PROJETO DA INDÚSTRIA QUÍMICA I - A
SEMESTRE 10
ENGENHARIA ECONÔMICA E AVALIAÇÕES
ESTÁGIO OBRIGATÓRIO EM ENGENHARIA QUÍMICA
HIGIENE E SEGURANÇA DO TRABALHO - A
PLANEJAMENTO E PROJETO DA INDÚSTRIA QUÍMICA II - A
TÓPICOS JURÍDICOS E SOCIAIS
TRABALHO DE CONCLUSÃO DE CURSO EM ENGENHARIA QUÍMICA

Total de Carga Horária: 4025

UFRJ
SEMESTRE 1
INTRODUÇÃO AOS CÁLCULOS DE PROCESSOS
CÁLCULO DIFERENCIAL E INTEGRAL I
CIÊNCIAS SOCIAIS E HUMANAS
QUÍMICA GERAL - EQ
INTRODUÇÃO AOS PROCESSOS QUÍMICOS E BIOQUÍMICOS
SEMESTRE 2
CÁLCULO DIFERENCIAL E INTEGRAL II
FÍSICA I - A
FÍSICA EXPERIMENTAL I
QUÍMICA ANALÍTICA
QUÍMICA ANALÍTICA EXPERIMENTAL I
QUÍMICA ORGÂNICA I - EQ
QUÍMICA ORGÂNICAL EXPERIMENTAL I - EQ
SEMESTRE 3
TERMODINÂMICA CLÁSSICA
CÁLCULO DIFERENCIAL E INTEGRAL III
FÍSICA III - A
FÍSICA EXPERIMENTAL III
QUÍMICA ANALÍTICA EXPERIMENTAL II
QUÍMICA EXPERIMENTAL - EQ
QUÍMICA ORGÂNICA II - EQ
SEMESTRE 4
FENÔMENOS DE SUPERFÍCIE E ELETROQUÍMICA
CÁLCULO DIFERENCIAL E INTEGRAL IV
ÁLGEBRA LINEAR II - EQ
EQUILÍBRIO DE FASES DE SISTEMAS MULTICOMPOSTOS
BIOQUÍMICA - EQ
QUÍMICA ORGÂNICA EXPERIMENTAL II - EQ
SEMESTRE 5
INTRODUÇÃO À QUÍMICA QUÂNTICA
FÍSICO-QUÍMICA EXPERIMENTAL
MECÂNICA DOS FLUIDOS
TERMODINÂMICA
ESTATÍSTICA
MÉTODOS NUMÉRICOS APLICADOS AOS PROCESSOS QUÍMICOS
MICROBIOLOGIA INDUSTRIAL
SEMESTRE 6
CIÊNCIA DOS MATERIAIS
TRANSFERÊNCIA DE CALOR
CINÉTICA QUÍMICA E REATORES
ANÁLISE INSTRUMENTAL
QUÍMICA INORGÂNICA - EQ
FUNDAMENTOS DE ENGENHARIA BIOQUÍMICA II
CIÊNCIA SOCIAIS E INTRODUÇÃO À ECONOMIA
SEMESTRE 7
MODELAGEM E DINÂMICA DE PROCESSOS
OPERAÇÕES UNITÁRIAS I
TRANSFERÊNCIA DE MASSA
PROCESSOS INORGÂNICOS I
PROCESSOS INORGÂNICOS - EXPERIMENTAL
PROCESSOS ORGÂNICOS
ADMINISTRAÇÃO E ORGANIZAÇÃO INDUSTRIAL
SEMESTRE 8
ENGENHARIA DE PROCESSOS
CONTROLE E INSTRUMENTAÇÃO DE PROCESSOS
OPERAÇÕES UNITÁRIAS II
ENGENHARIA DO MEIO AMBIENTE
PLANEJAMENTO E AVALIAÇÃO DE PROJETOS
SEMESTRE 9
SEGURANÇA DE PROCESSOS E PREVENÇÃO DE PERDAS
LABORATÓRIO DE ENGENHARIA QUÍMICA
TECNOLOGIA ORGÂNICA EXPERIMENTAL
SEMESTRE 10
ESTÁGIO SUPERVISIONADO

Total de Carga Horária: 3.600

Digital Transformation of the Natural Stone Sector

Amaral, Ana. Oliveira, Pedro

CTCV - Technological Centre of Ceramic and Glass

STRUCTURED ABSTRACT

Purpose

The CTCV - Technological Centre of Ceramic and Glass, in cooperation with Assimagra - Portuguese Association of Marbles, Granites and Related Branches have been developing a project called "The Stone4.0 Age - a Digital Transformation of the Stone Sector", whose objective is to support SME in the incorporation of industry 4.0 concepts and practices, empowering companies and providing digital tools that are adjustable to the reality of each organization.

Design/methodology/approach

The project began with a benchmarking study on the use of digital tools among companies in the sector, analyzing their applicability and scalability, covering extractive, transformation and trading companies. The benchmarking was supported by a questionnaire to diagnose the state of maturity of companies in the natural stone sector towards the challenges of industry 4.0 and digitalization and, in this way, to better understand their reality and needs.

Findings

This case of study concludes that companies recognize the added value of digital tools as vehicles that facilitate access to information in real time and data processing. However, its use still has gaps.

Customizable digital tools were developed, in the form of guides, to respond to the requirements of continuous improvement of the global efficiency of processes to create value, optimize their potential and drive companies towards the digital use of documentation.

Research limitations

The representativeness of the sample is small, given the size of the sector.

Keywords: Digital Transformation, Benchmarking, Digital Tools, Natural stone.

Paper Type: Case of Study.

INTRODUTION

The Project "The Stone4.0 Age - the Digital Transformation of the Stone Sector", aims to support SMEs in the natural stone sector in the incorporation of Industry 4.0 concepts and practices, empowering companies and providing digital tools adjustable to the reality of each organization.

In developing this work, it was -found that there is a perception in the industry of the advantages of tool digitization, namely:

- Reduction of time associated with data management and processing;

- Creating flow and increasing the speed of response in the supply of the service or product.

- Orientation towards the implementation of continuous improvement practices focused on adding value to the market;

- Greater control and specificity of industrial costing (maintenance, production and HR domains, including product subcontracting).

However, some lack of knowledge about digitization and its practical application persists.

The project focused on the Production Control Systems (PCS) and the Digital Tools used to support the management of these systems.

A specific questionnaire was prepared with the aim of diagnosing the state of digital maturity of companies in the natural stone sector, regarding the challenges of Industry 4.0 and digitalization, and thus to better understand their reality and needs.

The questionnaire was structured to allow knowing the state of the art in the national companies of the natural stone sector, in order to obtain reliable information that would allow characterizing the sector at various levels.

The topics covered were:

- General Characterization of Companies;
- Legal and Regulatory Compliance;
- Digitization of the Production Control System or Quality Management System;
- Technological Resources/ Digital in the Company;
- Qualitative Cost Structure;
- Key Production Indicators (management, production, maintenance).

The generality of the stone sector has human resources with extensive experience, a determining factor for responding to customer requests, by providing an appropriate service and product, often of an innovative nature. However, the sector needs to strengthen its Production Management Systems by introducing improvement tools that leverage the response, in order to make it quicker and more agile, so that the process is as efficient as possible. The companies in this sector, although they may already have implemented production control systems, have some gaps, namely in the requirements associated with quality management and organizational support processes, requirements that are - highly valued by their clients. In order to support companies to fill these gaps, proposals of Digital Tools were developed in a document called Guide.

The i4.0 Production Control System Digital Tools Guide aims to support companies in the implementation of these tools, optimizing their potential and pushing companies towards the digital use of documentation, with the access and communication ease they provide.

A direct and objective language was used to help companies with a lower degree of digitalization implementation to have a pragmatic vision on the subject and to want to improve their performance through the adoption of digitalized documentation and the acquisition of data in a format that facilitates its analysis.

The structure of the guide was defined in order to allow it to present a simplified and attractive approach to awaken the interest of companies in the advantages of these tools in improving organization, systematization of practices and consequent efficiency of production processes.

Each tool or methodology is addressed under the following headings:

- Purpose of using the tool;
- Contents;
- Applicable activities;
- Link to tool.

The digitalization of documents and records allows access to a large volume of data in real time and its knowledge is an ally of integrated management and contributes to decision making in a faster and more informed way.

RESEARCH METODOLOGHY

Questionnaire

The questionnaire designed to ascertain the state of the art regarding the digitalization of organizations covered the items previously mentioned and, with its analysis and data processing, is intended to be a benchmarking element for organizations to situate themselves in relation to the existing state of implementation in the sector. The objective was to obtain an image of the moment each organization is going through and, through concrete data, to compare its performance with that of other organizations, so as to be able to identify areas for improvement that will take their organization to a higher level.

The questionnaire was organized by activity areas, guiding companies to the questions that apply to their reality.

In addition, we sought to provide quick-answer questions through a choice of options:

1. Yes/No;

2. On a gradual qualitative scale, according to the level of implementation and reality of each company:

- Doesn't exist;
- Under implementation;
- Exists;
- Exists and is an effective improvement tool.

3. Questions with quantitative answers had available answer classes with intervals adjusted to the question.

This questionnaire was made available online, on the Google platform, with a view to constituting a facilitating route for companies to complete it, either via PC or mobile phone.

The information provided was treated as strictly confidential.

The information collected through the questionnaire allowed to have a perception of the digitalization level of the natural stone companies and knowledge of other indicators, namely the energy consumption, covering fuel and electric energy component.

As a methodological note, it should be noted that, when preparing the charts and presenting the - results, we chose to present the percentages without decimals. However, in some cases, the rounding performed by the support programme (excel) led to some situations in which the total sum is not 100, and may differ by one value at most.

Data collected and representativeness

In order to obtain representative information, the questionnaire was disseminated and made available to the companies in the natural stone sector associated with Assimagra, a total of 323 companies, by sending a circular letter appealing to the participation of the companies in its completion.

The universe of companies contemplated intended to include more than 300 companies, of various activities and sizes, with different levels of technological and digital resources and producers/manufacturers of a wide variety of products, with geographical distribution throughout the country.

Twenty-six responses were received from the contacted companies, which constitute the sample under analysis and it is on the data collected from this universe that the results of this study are presented. The majority of the companies, representing 42% of the responses received, are dedicated to the Transformation activity. The remaining companies are distributed between Extraction/Transformation activities - 38% and Extraction - 19%.

Figures 1 and 2 illustrate how the participation of companies was distributed, indicating their geographical location and the areas of activity they represent.

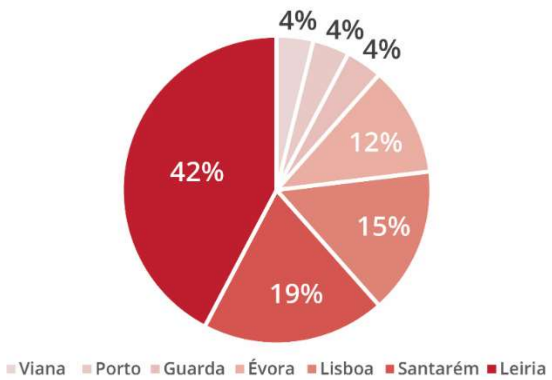

Figure 1 – Percentage of companies by districts

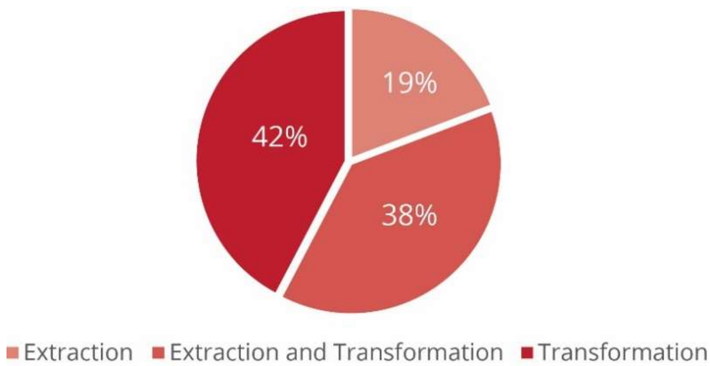

Figure 2 – Percentage of companies by activity

Most companies, around 80%, are located in the districts of Leiria, Santarém and Lisbon. The Alentejo, through the district of Évora, has a representation of 12%.

In terms of annual turnover, most companies invoice between 1 and 3 million euros. This is a strong exporting sector, where 42% of the companies export more than 80% of their production. Only for 12% of the companies does the export component represent less than 40%. However, there are situations in which the sale of the product on the national market is a step in the circuit to export, as larger companies sell abroad products acquired domestically.

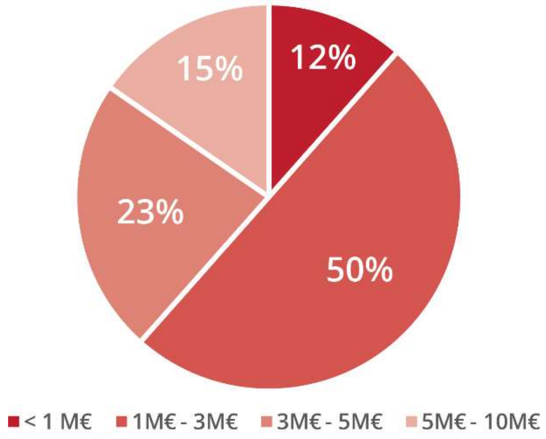

Figure 3 – Annual turnover

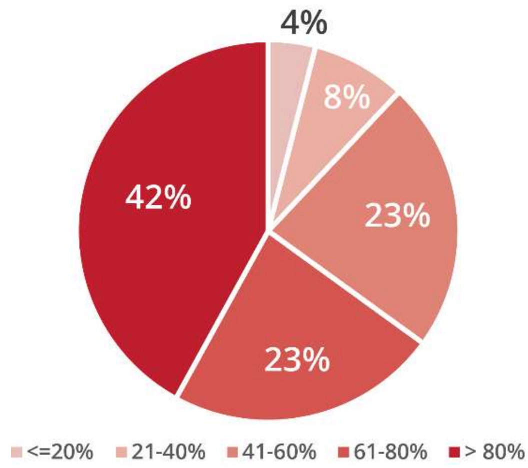

Figure 4 - Annual percentage of exports

The level of schooling is very similar in the Extraction and Transformation sectors. Most workers are educated up to the 9th grade and a low percentage (around 10%) are educated at secondary level. The low level of schooling of the generality of people can prove to be an obstacle in the digitalization of companies and in the introduction of new tools.

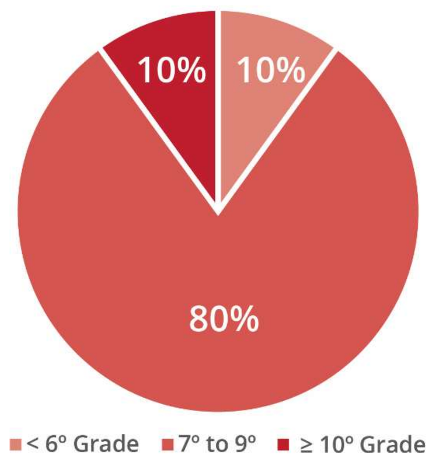

Figure 5 - Majority level of schooling in Transformation companies

Development of digital tools to support the Production Control System and tutorials.

The aim was to provide a set of digital tools to support some examples of documents of the Production Control System, namely:

- Raw materials and finished product control plans;
- Work instruction for dimensional control;
- Production and maintenance records;

- Calibration plan, Equipment sheet, Calibration acceptance sheet;
- Non-conformities follow-up record;
- Documentary control record;
- Declaration of Performance – DoP;
- Procedures (e.g. Document Management, Handling of Non-conformities and Corrective Actions).

The development basis for this documentation was based on the main specification standards applicable to natural stone products as a reference for the control tests to be performed, periodicity and the admissible tolerances for each characteristic of the final product.

In addition, and in order to facilitate the implementation and use of the tools developed, tutorials were prepared to explain how to complete them, with demonstrations of data entry and obtaining validation of product conformity.

RESULTS

The results obtained in the questionnaires were worked out and graphs were constructed, of which the one shown in figure 6 stands out, on the level of digitalization of the organization's production control systems and quality management system.

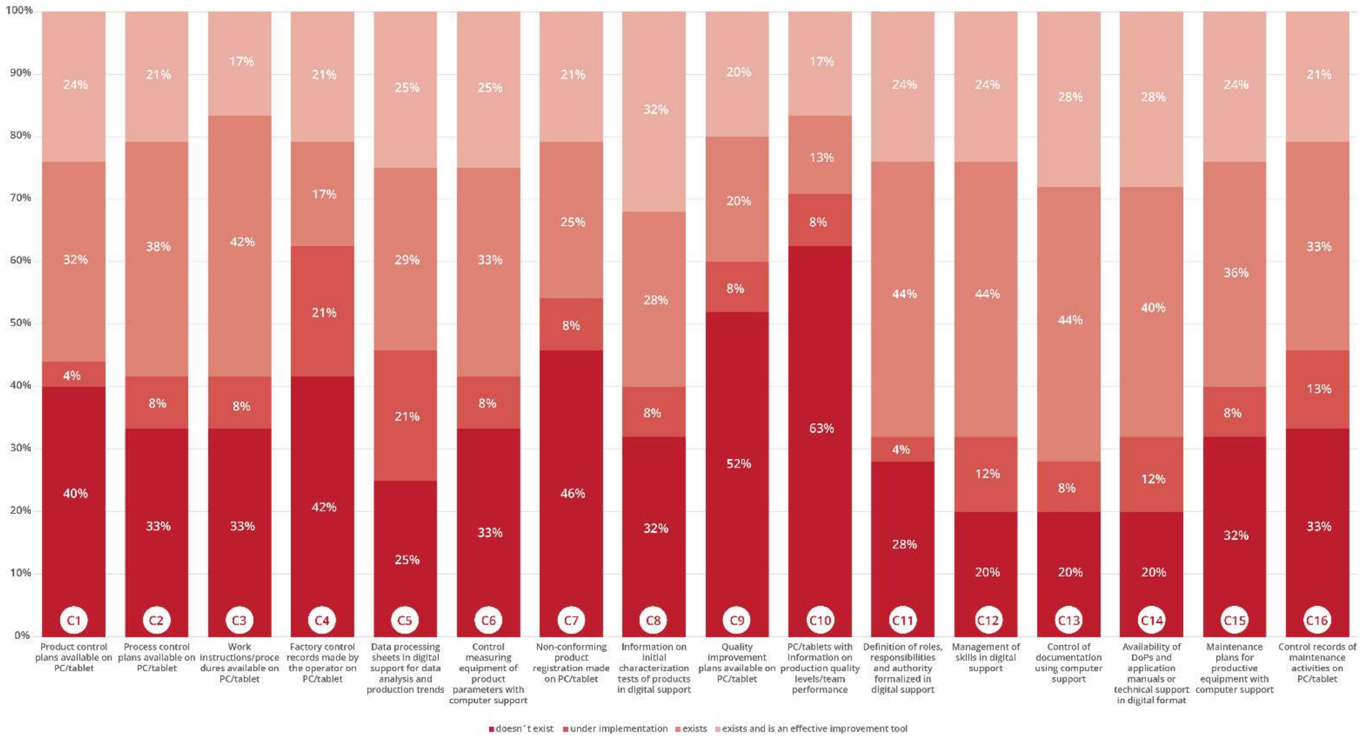

Figure 6 - Digital Level of Production Control System/ Quality Management System

When questioned about the degree of digitalization existing in the companies of the natural stone sector, in terms of the transmission of information and documentation supporting to the Management systems, including documents and records, figure 6 allows some conclusions to be drawn:

- 72% of the companies state that they have centralized documentation control using computer support (column C13)

- Around 60% of the companies have digital documentation related to management systems (product control plans, process control plans, work instructions - columns C1+C2+C3). However, this conclusion is mostly applied to documents, since in 42% of the companies records of production control parameters are made on paper (C4).

- In terms of internal communication, there is a large potential for improvement in the use of digital resources, as 63% of the companies do not make available information on quality levels and 52% do not disseminate quality improvement plans via PC or tablet (C9 and C10).

- The use of digital support is used by almost 70% of the companies to send information to clients, namely with regard to Declarations of Performance (C14).

- With regard to human resources, skills management (including the assessment of training needs, training plan, employee CV updating), is supported on a digital basis in 68% of the companies, and also covers the definition of roles and responsibilities (C11 and C12).

- The monitoring of the control of measuring equipment and monitoring of parameters in digital format is done by 58% of the companies (C6).

- 60% of the companies have digital support for the maintenance of production equipment, although records in the same format are less expressive. (C 15 and C 16).

The lower uptake of records in digital format may be related to the low levels of training of operators and may here pose questions associated with the digital skills of the sector's human resources.

Around 25% of the companies recognize the added value of digitalization associated to management systems and consider it to be an effective improvement tool.

The characterization of companies with regard to the level of technological resources they have was carried out separately for companies with different activities, so that the questions were applicable to each sector. The graph in Figure 7 represents the responses of companies with Transformation/Extraction and Transformation activities.

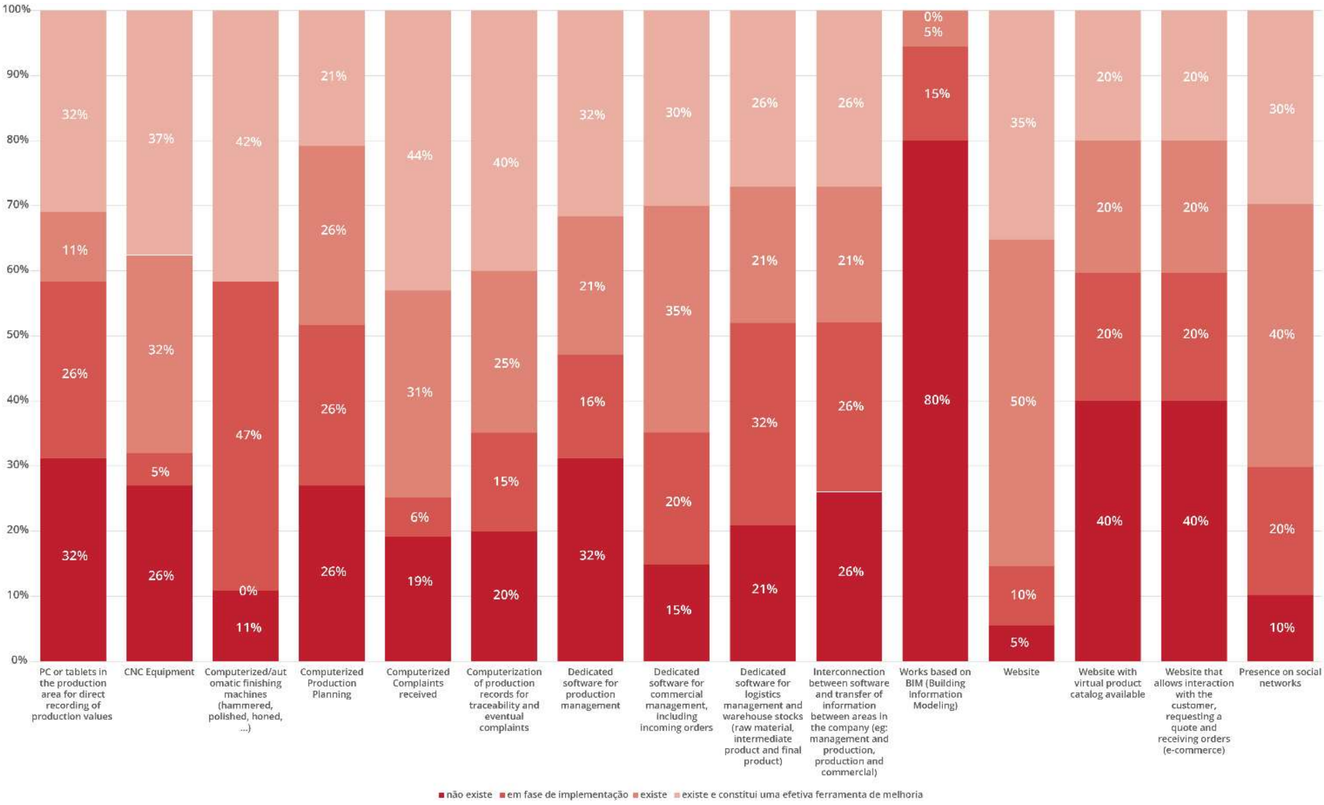

Figure 7 - Technological and digital resources - Extraction and Transformation

In the companies of the Transformation and Transformation/Extraction activities, figure 7, it can be seen:

- The companies value the computerization of the sectors, highlighting the existence of dedicated software for the different areas of the company. The preferred sector is the commercial one, followed by logistics and warehouse stock management and, finally, production. Approximately 50% of the companies have this support to manage production and are able to take advantage of the interconnection between the different sectors.

- The sector is modernizing in terms of the complexity and automation of processes. 89% of the companies state that they have computerized machines to finish the product and 69% have CNC equipment. It is at the level of records that a reduction of resources is observed, as more than half of the companies do not use computers or similar equipment to collect data. This fact may be related to the low training of the workers.

- When it comes to computerizing data, priority is given to complaints (75%), followed by production records (65%) and finally production planning (47%).

The interconnection between software and the transfer of information between areas in the company (e.g. management and production, production and commercial) occurs in about 50% of the organizations).

- Regarding the website and its potential: most of the companies have a website, only 5% gave a negative answer. In these companies there is an advance in the use of the website, in relation to the Extraction companies, as 40% of them provide a product catalogue and interact with the client through this means.

- 70% of companies use social media presence as a complement to communication and 20% are in the implementation phase.

- The use of new methodologies, such as BIM - Building Information Modelling, for the virtual visualization of the final applied product, including all relevant information associated to the product, is only used by 5% of the companies.

Globally, it can be seen that the natural stone sector is undergoing a modernization process, with an interesting number of companies already having technologically advanced means to meet the demands of more demanding markets.

In order to encourage some organizations at a more elementary stage of digitization to improve this situation, some digital tools have been developed whose purpose and content is explained in the following tables.

Customizable digital tools were developed, in the form of guides, with individualized links for each tool, of collective appropriation. The i4.0 Digital Tool Guides for Production Control and Quality Management Systems intended to respond to the requirements of continuous improvement of the global efficiency of processes to create value, optimize their potential and drive companies towards the digital use of documentation, with the ease of access, communication to the team and action, which they provide in a format that facilitates their analysis.

The information for the record sheets is given as an example.

Record Sheets

Purpose of the tool
Evidence of compliance with the pre-established control and monitoring. The aim is to keep proof of the measurement of the parameter whose monitoring is defined at a certain frequency. Verify that the product made meets the specifications defined to be compliant.

Content
The record sheet is prepared in such a way to contain fields that allow the recording of all parameters/characteristics that are defined in the control plan and that must be controlled. For the examples of the digital tools provided, the respective product standards and the tolerances defined for geometric features, e.g. length, width, flatness, thickness, were analyzed. A comparison is made with the specification and a decision is made on the conformity of the value, i.e. the conformity of the product. The values that fall outside the control ranges, i.e. exceed the defined specifications, both by defect and by excess, shall be indicated. Nonconforming products shall give rise to corrective actions or corrections so that the product returns to the expected values and to avoid the recurrence of the causes of non-conformity.

Applicable activities
Applicable for all activities in the natural stone sector. Applicable to all phases of the production process, from the reception of raw materials to the final product.

Links to the tool and the explanatory tutorials
EN 1469 - Slabs for wall cladding **Link to the tool** **Tutorial link**

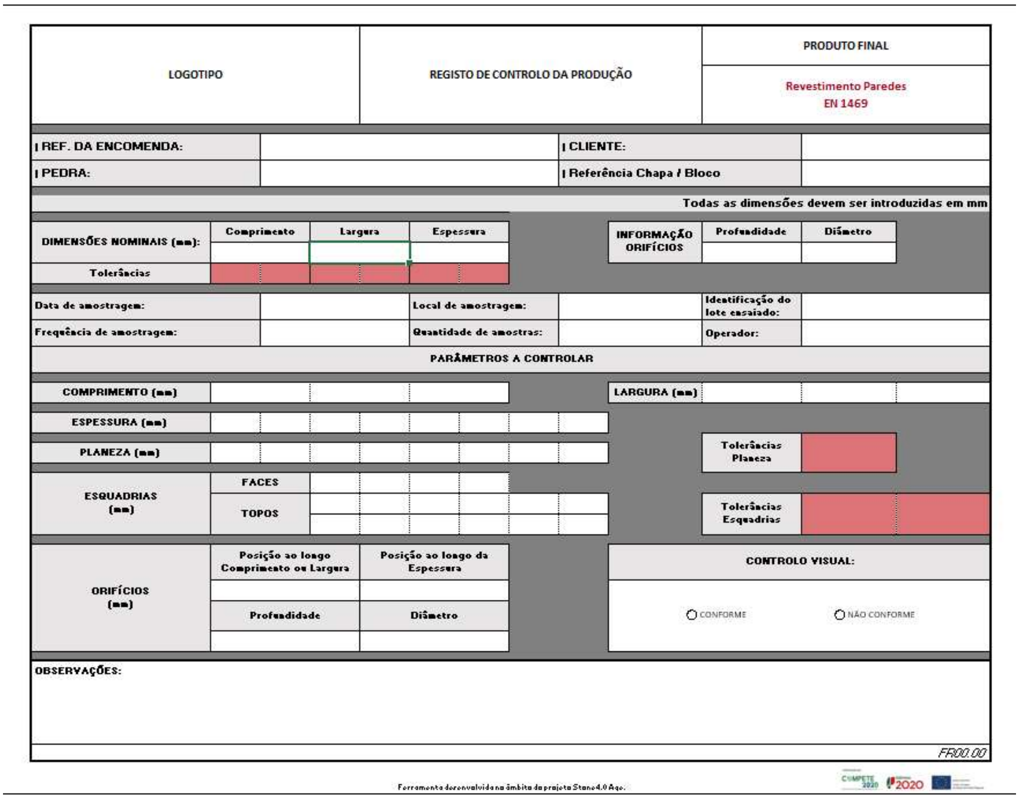

Figure 8 - Developed record sheets

The tutorials show that, according to the conformity of the values measured in the final product with the tolerances defined in the standard, the cells are given the colours green and red for easy perception by the user.

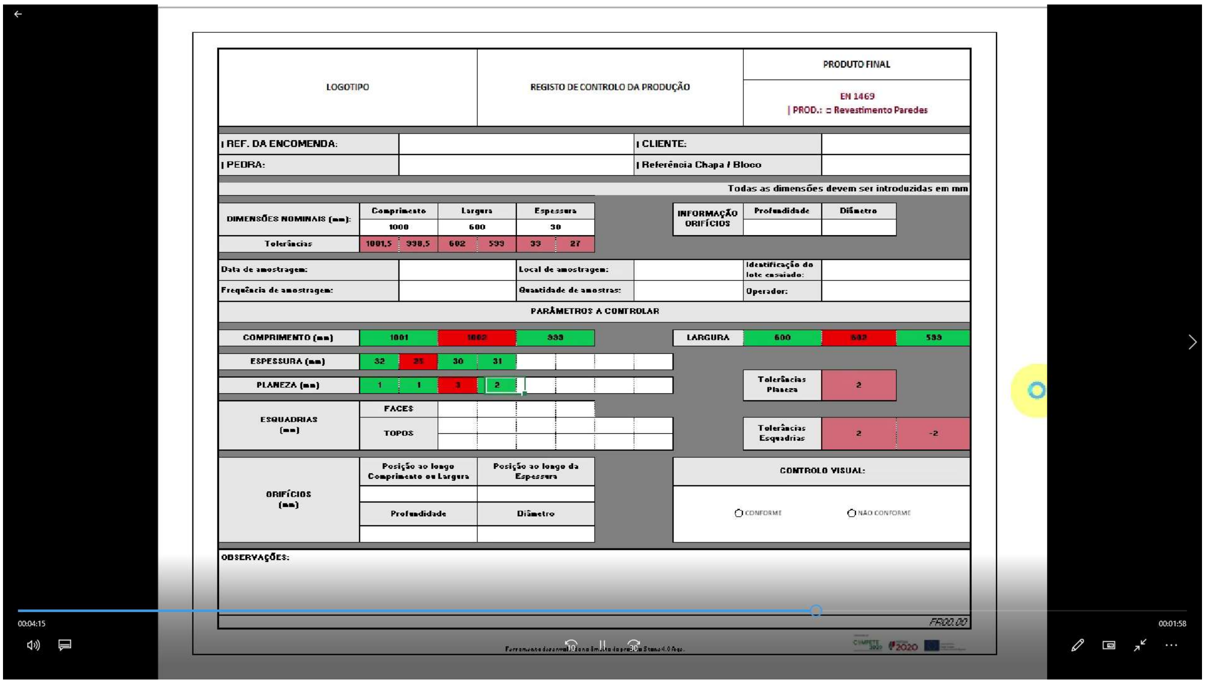

Figure 9 - Developed tutorial to support the filling of the record sheets

CONCLUSIONS

Gradually, the use of documents in digital format has been adopted by organizations as a way to ensure a more effective management, based on faster and easier access to data. The current context of a global economy, increasingly competitive, requires companies to adopt management models that allow them to increase the efficiency of their processes, improve the quality of products and services and reduce production costs.

It is in this context of seeking excellence in management and a qualitative leap supported by Industry 4.0/digitalization of companies, that digital tools gain importance as facilitators of access to real-time information and data processing, to enable decision-making in a fast and objective manner, supported by facts. The objectives of digitalization include the continuous improvement of the efficiency of all processes and the search for differentiating solutions that meet customer needs.

This work was intended to contribute to the understanding of digital maturity in the natural stone sector. The adhesion of the companies to the project was restricted. From the 323 companies contacted, only 26 responded. With the collected data, the analysis of the questionnaire results is carried out, in its different aspects, with emphasis on the level of implementation of technological resources and the digitalization of processes. This approach is presented below considering, separately, the relationship with the Production Control System and the Management System.

Fitting with the Production Control System

CE marking is a legal requirement applicable to construction products that covers natural stone products. To be able to affix the CE marking, the manufacturer must comply with the provisions of the approved product standards, both at the level of the Production Control System (PCS) and at the level of the initial type tests for product characterization.

Some conclusions arising from the data collected through the questionnaire.

1- 73% of the companies in the sample state that they have a PCS and 4% are in the implementation phase. It is a figure that highlights the perception of the importance of compliance with the legal requirement that is the affixing of the CE marking and it is urgent that companies in default move forward with the process.

2- The use and control of centralized documentation, using computer support, exists in 72% of the companies.

3- Around 60% of the companies have digital documentation related to production management and control systems, such as product control plans, process control plans and work instructions. However, in 42% of the companies, records of production control parameters are made on paper, possibly due to the low training of workers to use computerized means. The analysis of the information on data processing is interesting when compared to digital records, because it shows that the data collected is transferred to computer support in order to analyze trends and be able to work more easily with the information. It remains to make the leap so that this acquisition is done in real time, directly in production, when the parameters are measured.

4- The use of digital support is used by almost 70% of the companies to provide customers with technical information on the product, namely regarding the Declarations of Performance. This document, which is mandatory under the CE marking, is mostly made available through the website.

5- The registration and handling of complaints is largely supported by the computerization of information, in 75% of the companies.

6- The measurement of product parameters is done with monitoring and measuring equipment, whose control is the responsibility of the manufacturer, with the aim of ensuring the reliability of the measured values. 33% of the companies do not carry out this control based on digital support. Doing so allows relying on additional help and reminders to carry out the calibrations and internal checks, without failures.

7- The monitoring and control of workers' skills and their progression is managed with IT support in almost 70% of the companies.

Fitting in with the Management System

The implementation of a Management System according to a standard presupposes the compliance with the set of requirements recommended by it and the compliance with the applicable regulatory and statutory requirements, i.e. the legal requirements. In this way, being the CE marking a legal requirement, it can be concluded that the Management System covers the fulfilment of the practices foreseen in the PMS and goes beyond that.

1- 35% of the companies in the sample have a certified Quality Management System, which is substantially lower than the number of companies with a PMS.

2- The QMS and the processes can be managed using the PDCA cycle (Plan-Do-Check-Act). The formalization and monitoring of the various stages, their internal disclosure and the commitment and participation of all those involved is greatly facilitated by the existence of means of sharing information and collecting contributions.

3- Digitalization and the use of digital means are facilitators for the follow-up and control of management support performance indicators, whose existence is a normative requirement. What cannot be measured cannot be improved, there must be a starting point, to be compared, as actions are implemented and their outcome monitored. The collection of data and the timely calculation of indicators associated with production, allows for quicker action/reaction in relation to the problems detected. The interconnection between software from different areas (e.g.: commercial and production) exists in more than 40% of the companies and it is a way of disseminating the necessary information by process interveners and decision makers.

4- Another aspect of the QMS that benefits from the use of digital support is the approach to risk. After the identification of risks and their classification, their treatment is supported in action plans that often include several areas and interlocutors. The sharing and monitoring of information on progress and setbacks in an interactive and dynamic way is only used in 40% of the companies, whose improvement frameworks exist in digital form. The identification and classification of risks plays a key role in defining the organization's strategy and objectives. There is a potential for growth in the use of digital technologies as a basis for management decisions.

5- The dynamics of improvement, inherent to the QMS, disseminated in a generalized manner, for example displayed on tables or made available on PCs/tablets, through action plans and respective follow-up and verification of effectiveness, is a practice in 30% of the companies (local tables with information).

6- The relationship with customers has to be increasingly close and quick in responding to their requests. 75% of the companies resort to computerizing the complaints received, as a means of dealing with them more quickly, but also of keeping a history of occurrences and respective resolutions.

7- Also included in the QMS requirements is infrastructure management, so as to guarantee the availability, under the best conditions, of production equipment, as fundamental elements for the production of compliant material, complying with specifications. The preparation of maintenance plans, maintenance records and data analysis is based on digital resources in about 60% of the companies.

Final notes

Digitization aims to align quality management/systems with Industry 4.0 to enable:

- greater efficiency;
- performance increase;
- innovation;
- more resilient business models.

The industry is in a phase of renewing the paradigm of work and the use of technological resources in order to eliminate:

- Inefficiencies caused by fragmented systems;
- Manual calculations and mismatched metrics;
- Quality/improvement teams lack multifunctionality;
- Internal and supplier communication problems - different languages.

We conclude that a significant number of companies are aware of the advantages associated with digitalization and the inevitability of its incorporation. Around 25% of the companies recognize the added value of incorporating these technological tools and resources as fundamental instruments for sustainability and continuous improvement.

Integrating the potential of digitalization in the natural stone sector is a work that must be started as soon as possible. A few guidelines stand out:

- Reinforcement of skills: recruitment of employees with higher levels of digital skills. In parallel, investment in training programs that provide companies with skills and knowledge in digitalization, both at top management level and in technical areas and field work. The change of mentalities is essential for the acceptance of "doing things differently", more digital.
- Digital infrastructure: dematerialization of data and implementation of just-in-time reporting schemes are the basis of Industry 4.0. Automatic collection and processing, immediate reporting to measurers and decision-makers - timely action - saving resources.
- Advanced data analysis: existence of integrated programs/systems for management and planning, based on a broader knowledge of the information and a comprehensive view for conscious decision-making.
- Creation of reliable indicator networks: introduction of tools that make dashboards available on time, in an intuitive manner, resulting from the need to know and monitor a set of indicators to support decisions.

- Top management involvement: joining digitization programs is indispensable for the commitment of the team and as a starting point for digitization projects to be understood as a priority by all.
- Scope: Digitization can start in the production area, but the advantages of interconnecting information covering several areas such as accounting, administrative services, customer service, purchasing and subcontracting, etc. should be considered.

In a vision directed at the short/medium term future, it is envisaged:

1- Better product traceability in the production process and dispatch, with the introduction of unequivocal identification systems (e.g. bar codes), complemented by optical reading of these codes during the manufacturing process and dispatch.

2- Increasing complexity and the degree of automation of production equipment in transformation companies in the sector to achieve levels of product excellence that make it reach the most demanding markets.

3- Connectivity between systems and equipment. Remote articulation and operation of production equipment. Monitoring and visualization of the factory's reality with remote monitoring programs and consultation through mobile devices.

4- Emerging need for management platforms (ERP - Enterprise Resource Planning type) that help companies standardize their processes, in order to make managers' lives easier. Based on data analysis, they allow the elaboration of a diversity of graphs, based on the establishment of dependency and interaction relationships, in order to sustain and leverage decision making.

5- Digital empowerment of customer interaction. Integration of multiple channels (website, blog, social media platforms, etc.) to communicate and receive feedback. Possibility for the customer to access and follow the processing status of their order during the production and shipping process.

REFERENCES

- Regulation (EU) nº 305/2011 of the European Parliament and of the Council of 9 March 2011 laying down harmonized conditions for the marketing of construction products.
- Ferreira, M. and Baio Dias, A. (2007), “Guia para a implementação de um Sistema de Controlo da Produção de tijolo cerâmico, telha cerâmica e acessórios”, Centro Tecnológico da Cerâmica e do Vidro, Coimbra.

- Ferreira, M. and Baio Dias, A. Anda Ilharco de Moura, G. (2007), “Guia para a implementação de um Sistema de Controlo da Produção de pavimentos e revestimentos cerâmicos”, Centro Tecnológico da Cerâmica e do Vidro, Coimbra.

- Oliveira, H. (2010), “A Marcação CE e as Directivas Nova Abordagem”, Universidade de Aveiro, Aveiro.

- Casal Azevedo Moura, A., coord. Esteves Henriques, A. (2008), “Guia prático para a marcação CE dos produtos em pedra natural”, Direção Geral de Energia e Geologia, Lisboa.

- Marcação CE, https://europa.eu/youreurope/business/product-requirements/labels-markings/ce-marking/index_pt.htm

Supply Chain Quality Management 4.0: Systematic literature review and conceptual framework

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STRUCTURED ABSTRACT

Purpose – The research aims at providing new insights and a collective perspective regarding Supply Chain Quality Management 4.0 (SCQM4.0), an integration of all three concepts - Industries 4.0, Quality Management, and Supply Chain Management.

Design/methodology/approach – A thorough review of historical developments and existing integration trends among Industries 4.0, quality, and supply chain approaches is conducted. This work establishes a knowledge base on research topics, issues of integration, and synergies concentrating on thedeeper integration with supply chain operations.

Findings – Not only does this article introduce the term SCQM4.0 and propose a definition for it, but it also contributes a novel conceptual SCQM4.0 framework. Assessing the gaps, opportunities, and benefits identified in the literature, the conceptual SCQM4.0 framework builds on the high potential of the SCQM4.0 constructs to achieve successful governance and implementation.

Research limitations/implications – Striving towards a successful SCQM4.0 implementation, the proposed SCQM4.0 framework will be a "road map" for businesses to develop fully and actively in supply chain operations, bringing quality products and services for the company. Industry practitioners are encouraged to perform gap analysis and direct the implementation of the strategy to establishing an excellent SCQM4.0.

Originality/value – This is one of the pioneering studies that integrate all three concepts (Industrie 4.0, Quality Management, and Supply Chain Management), connecting the link, and discovering more synergies to support the future development of more holistic management models. SCQM4.0

is expected to expand on the strengths, and synergies, and establish relationships between technologies 4.0, quality, and supply chain, contributing to a pioneering and quality supply chain.

Keywords: Industries 4.0, Disruptive Technologies, Quality Management, Supply Chain Management.

Paper type: Conceptual paper

1. INTRODUTION

The phrase "Fourth Industrial Revolution", known as Industry 4.0, was first coined in 2011 by a panel of scientists who were developing a high-tech strategy for the German government to promote the computerization of manufacturing (Navas et al., 2020). The term was introduced publicly in the same year at the Hannover Fair. Since that time, this topic has gradually become a highly interesting trend in industry and academia (Navas et al., 2020). Currently, the topic has gained global attention as it has been part of the agenda of the World Economic Forum since 2016 (Hofmann and Rüsch, 2017).

This high interest lies in the fact that Industry 4.0 has the potential to transform the way value is created and delivered as well as how companies compete (Frederico et al., 2019). More broadly, countries with the foresight in developing Industry 4.0 initiatives and capabilities will remain strong in the globally competitive market (Sony et al., 2020). Hence, they are of great interest.

Industry 4.0 integrates the so-called cyber-world with physical systems by using innovative and disruptive technologies such as embedded systems, semantic machine-to-machine communication, cyber-physical systems (CPS), internet of things (IoT), cloud technologies, big data analytics (BDA), radio frequency identification (RFID), automatic identification and data acquisition (AIDC), block chain, robotics, augmented reality, simulation, and 3D printing (Kannan and Garad, 2020, Navas et al., 2020, Mazzuto and Ciarapica, 2019, Sriram and Vinodh, 2020). These new technologies will have implications for a multitude of business areas, including the development of new products and services, operations, maintenance, work environments, people and organization management, risk management, business models, etc., which leads to significant changes to the supply chain (Kannan and Garad, 2020, Mazzuto and Ciarapica, 2019, Navas et al., 2020).

Several articles have been recently written on the integration of Industries 4.0 with Quality Management and Supply Chain Management (Ardito et al., 2019, Bienhaus and Haddud, 2018, Hofmann and Rüsch, 2017, Kannan and Garad, 2020, Lu, 2017, Barreto et al., 2017, Tjahjono et al., 2017, Muthusami and Srinivsan, 2018), and have established a knowledge base on research topics, issues of integration and synergies concentrating on deeper integration with supply chain operations. However, there are no, or very limited assessments conducted from the prism of all three (Industries

4.0, Quality Management and Supply Chain Management), connecting the link and discovering more synergies to support the future development of more holistic management models. This research aims at providing new insights and a collective perspective regarding Supply Chain Quality Management 4.0 (SCQM4.0), an emerging research theme in operations research.

Apart from introducing the term SCQM4.0 and proposing a definition for it, this research serves the purpose of developing a new conceptual SCQM4.0 framework (Figure 1). This SCQM4.0 model is expected to provide a clear evolutionary pathway underpinned by the SCQM4.0 constructs. Based on this, the organization will achieve perfection in supply chain quality management and enhance the company's position in the market if it can determine the place and scope of solutions in the SCQM4.0 roadmap. From there, the company will fully comprehend what needs adding or modifying to approach a successful SCQM4.0.

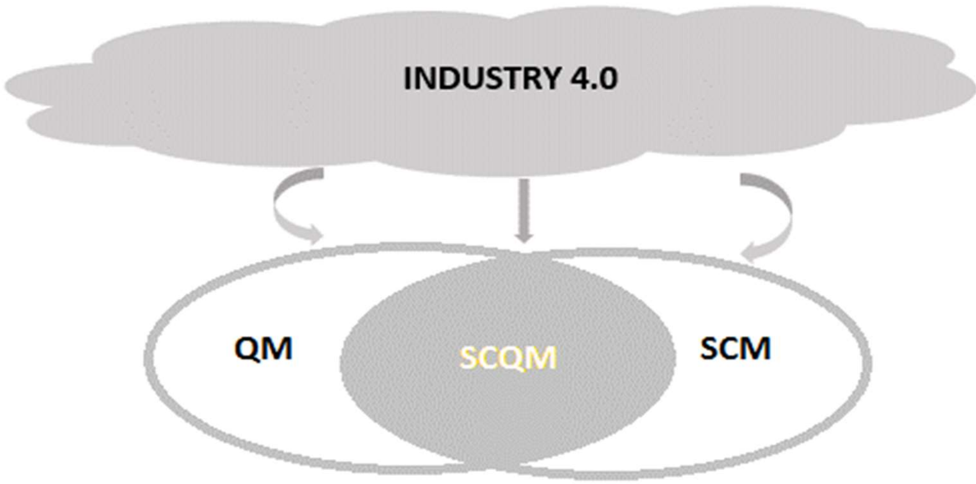

Figure 1 – Research idea

The next sections of this paper cover the following: Section 2 describes the literature on the integration of Industries 4.0 with Quality Management and Supply Chain Management, prior to introducing the SCQM4.0 concept. The research stream of SCQM4.0 is then depicted and discussed to pave the way for the development of conceptual framework. Finally, the conclusion provides recommendations for future research directions.

2. LITERATURE REVIEW

2.1 Systematic literature review protocol

A systematic literature review was carried out to create a relevant analytical model for SCQM coordination and integration over the years. The essence of this systematic review is to assist in establishing solid knowledge bases, facilitate in-depth exploration and analysis, and provide the methodological rigor for solving problems through clear and extensive document scanning, specific notes, criticality assessments, and mapping of the "knowns" and "unknowns" to the subject. With the areas under investigation (Briner and Denyer, 2012), insights are gained as a result of assessments aimed at stimulating future thought and theory building in the field of strategic management, which is being explored (Webster and Watson, 2002). Moreover, systematic review is considered a powerful and testable method that facilitates the development of theories, acknowledges the guidelines, and draws conclusions (Vos et al., 2015). The systematic review process ensures a centralized, transparent, and repeatable assessment with respect to research inquires in a high degree of confidence due to reduced risk of bias ((Briner and Denyer, 2012); (Kitchenham, 2004); (Robertson et al., 2003)).

The fundamental process for a comprehensive and coherent systematic literature review is structured in three phases: planning, conducting, and reporting (Robertson et al., 2003), presented in Table 1.

Table 1: SLR protocol	
Phase 1 Planning	**Search Strings** *SC4.0:* Supply Chain 4.0, Supply Chain and Industry 4.0, Supply Chain and Digitization, Fourth Industrial revolution and Supply Chain, Internet of things and Supply Chain, Block chain and Supply Chain *Q4.0:* Quality 4.0, Quality and Industry 4.0, Quality and Digitalization, Fourth Industrial revolution and Quality, Internet of things and Quality, Block chain and Quality *SCQM4.0:* Supply Chain and Quality and Digitization, Supply Chain and Quality and Industry 4.0, Fourth Industrial revolution and Supply Chain and Quality, Internet of things and Supply Chain and Quality, Block chain and Supply Chain and Quality **Literature Databases** Scopus, Elservier, Emerald, Wiley Online Library (Wiley), Taylor & Francis, Springer, Inderscience, Informs PubsOnline, Ebsco and ProQuest, IEEE Xplore, Web of Science, and Google Scholar **Search Period** 2011 to July 2021
Phase 2 Conducting	**Searching** Based on Planned Criteria **Screening** Identification: Identify throughout database and abstract Eligibility: Review introduction and conclusion Included: Review full text

	Analysis Descriptive analysis and thematic synthesis
Phase 3	
Reporting	Establishing Constructs for Supply chain quality management 4.0 Concept Building a Conceptual Framework

2.2 Industries 4.0 and Quality management

In contemporary society, several companies struggle with quality issues. Evidently, in any industry, the number of recalled products because of poor quality are invariably a thought-provoking problem for the company. Traditional methods of quality management are confronted with responding to ever-changing customer needs with a sustained high level of quality. Further challenges are additional resources for R&D to develop new methods of quality, global standardization of standard quality, and increased quality when products are customized (Sony et al., 2020).

The integration of Industries 4.0 with quality management, namely Quality 4.0, is a new wave of innovative work in manufacturing (Sony et al., 2020). Quality 4.0 integrates manufacturing with cutting-edge technologies to maximize outputs, creating high-quality products and services while using minimal resources (Kannan and Garad, 2020). Moreover, Quality 4.0 practices target at creating new production systems that are designed to follow customer needs (Sony et al., 2020). The literature has lent insight into the application of digital technologies to quality management in various ways, for example, processing big data to improve design, conformance, and performance qualities of products and services (Mazzuto and Ciarapica, 2019). The recent development of affordable sensors, improved data acquisition systems, and rapid communications in the cyber-physical network of Industry 4.0 generate large amounts of data (Mazzuto and Ciarapica, 2019). A single machine by virtue of its being interconnected will collect big data that mainly revolves around its operating and maintenance conditions (Navas et al., 2020). These analyzed data enables customer needs to be understood thoroughly or holistically, helping organizations design a better balance in target variables, which is likely the cost and value of the product (Sony et al., 2020).

Recent advances in the field of business analytics, such as prescriptive analytics, have provided organizations with adaptive, automated, and time-dependent courses of action to capitalize on business opportunities (Soltanpoor and Sellis, 2016). Prescriptive analysis algorithms for design, conformance, and performance qualities offers a wide selection of solutions with scenario analysis in all three phases of quality planning, control, and improvement, ensuring human intervention in a manner that aids the finalization of the best choices (Soltanpoor and Sellis, 2016).

Another application of Quality 4.0 is the "smart factory" where an organization can monitor processes and extract data from real-time sensors to predict quality issues and maintenance needs of the organization (Navas et al., 2020).

Sony (2018) draws attention to the vertical integration of physical and information subsystems, e.g. actuators, sensors, Enterprise Resource Planning (ERP), and Systems Applications Programming (SAP), creating a flexible and reconfigurable production system. Moreover, this cross-organizational horizontal integration also results in the efficient production of products and services (Sony, 2018). Furthermore, Stock and Seliger (2016) integrate all product-centric operations, i.e. end-to-end integration, providing the Quality 4.0 module with an excellent opportunity to monitor the quality and reliability of the product (Mazzuto and Ciarapica, 2019). Product usage-related data through end-to-end integration of technologies 4.0 enhances the quality of design (Sony et al., 2020). Hence, customer needs can be mapped and consequently, better design products and services.

Some other applications in the literature can be (1) integration of the cyber-physical systems of the computational, network, and physical processes for the organization to identify quality problems (Kannan and Garad, 2020), (2) decentralized self-organization (Sriram and Vinodh, 2020), (3) new systems of distribution, procurement, and development of products and services (Bienhaus and Haddud, 2018, Sriram and Vinodh, 2020, Nair et al., 2019, Stentoft et al., 2019).

2.3 Industries 4.0 and Supply chain

Research streams on the integration of Industry 4.0 and Supply chain, videlicet Supply chain 4.0, in 2015 with an increasing number every year (Tjahjono et al., 2017, Muthusami and Srinivsan, 2018, Frederico et al., 2019). There are a great number of evidences for the successful application of disruptive technologies to supply chain management (Ardito et al., 2019, Bienhaus and Haddud, 2018, Büyüközkan and Göçer, 2018, Hofmann and Rüsch, 2017, Iddris, 2018, Tu, 2018, Wu et al., 2016, Brinch, 2018a, Barata et al., 2018, Barreto et al., 2017). Most research streams consider this aspect as a key driver delivering the cutting-edge performance transformation of Supply chain 4.0.

Web portals were introduced early in the supply chain digitization to improve information sharing (Dallasega et al., 2018). The most important feature of web portals is the ability to manage the workforce, requirements, documents, inventory, and equipment through IT-controlled communication centers, e.g. "peripheral networks" (Ajam et al., 2010). Tender-Space is an example of an online hub designed to help supply chains collaborate in a transparent, open, and fair manner to avoid errors [69]. The combination of web portals with web services and open-source technologies has led to the development of systems such as the service-oriented SC collaborator (Ajam et al., 2010). Further development is a web service collaboration framework for measuring and monitoring sustainability performance indicators, as well as information technology-based lean supply chain models (Chenga, 2011).

Another application of Industry 4.0 across the supply chain is cloud computing (Ardito et al., 2019). This solution has truly transformed the supply chain by providing real-time access to data from any location (Ardito et al., 2019, Büyüközkan and Göçer, 2018, Tjahjono et al., 2017) and improving collaboration (Frederico et al., 2019). While cloud computing is a rapidly expanding field of research, the application of this technology in a supply-chain context has not matured (Ardito et al., 2019). Studies show that the adoption of mobile communication technology with Internet technology (known as M-Internet) for supply chain management can improve the physical flow, sharing, and transmission of information in real-time, integrating and supply chain coordination, technology support, and safety-related issues (Barata et al., 2018). Cloud computing is considered to solve the challenges related to duplication or persistence of data as a result of the integration of diverse actors in the supply chain (Das et al., 2015).

A management information system framework can assist supply chains to align and improve coordination across organizations, provide and visualize information, and monitor performance(Dallasega et al., 2018). Management information system applications are interested in real-time supply chain management and the potential of real-time data collection tools to achieve a supply-demand matching (Dallasega et al., 2018). Real-time inventory tracking and demand changes help balance stock and meet demand (Muthusami and Srinivsan, 2018).

For tracking and locating items, these technologies involving RFID, Global Positioning System (GPS), Ubiquitous Sensor Network (USN), and Automated Materials Locating and Tracking Technology (AMLTT) show great potential for the supply chain by reducing errors and minimizing anomalies and random processes (Ergen et al., 2011), with less dependence on expensive raw materials (Young et al., 2010), shorter processing times and reduced labor costs (Dallasega et al., 2018). These technologies facilitate real-time inter-organizational communication (Dallasega et al., 2018) and increase productivity (Young et al., 2010).

Building information modeling specifically focuses on supply chain design, automated data collection, processing, and sharing through information management (Tang et al., 2013). Such designs describe operating models, procurement, processes, and control systems to monitor supply chain progress (Getuli et al., 2016, Dallasega et al., 2018). As a result, design quality and collaboration between supply chain parties can be markedly improved by engaging key suppliers directly from the design and information integration stages of the supply chain in building models (Dallasega et al., 2018). In this aspect, building information modeling is a powerful tool for integrating decision-making through visualization of the current state of the physical flow (Azambuja et al., 2012). This minimizes logistics costs, especially ordering, warehousing, and transportation costs (Irizarry et al., 2013). Dike and Kapogiannis (2014) argue that the successful implementation of building information modeling will improve cooperation among supply chain members, leading to better supply chain performance.

An important area that receives little attention in the supply chain 4.0 literature is 3D printing (Büyüközkan and Göçer, 2018, Iddris, 2018, Tjahjono et al., 2017, Kannan and Garad, 2020). Kothman and Faber (2016) investigate the potential impact of this innovative and disruptive technology on ecological supply chain performance. The authors found that 3D printing shortens lead times, integrates functions, and allows for reduced material use and logistics efforts. Furthermore, 3D printing presents sustainable ways to mass-produce customized products (Navas et al., 2020).This is a potential technology that can change many aspects of the conventional supply chain.

Sony et al. (2020) asserts that some of the challenges while implementing supply chain 4.0 are the acceptance of new technologies and the interoperability of digital subsystems for efficient operations of the production system. Therefore, many research streams offer solutions to overcome this challenge, setting the stage for successful implementation of supply chain 4.0, such as infrastructure practices (Blatz et al., 2018, Kannan and Garad, 2020, Nair et al., 2019, Sony et al., 2020, Sriram and Vinodh, 2020, Stentoft et al., 2019). Frederico et al. (2019) believes that the awareness of all supply chain members regarding to benefits and requirements of supply chain 4.0 is essential. Therefore, top management support plays an important role in creating such awareness with the involvement of all relevant stakeholders (Sriram and Vinodh, 2020, Stentoft et al., 2019, Nair et al., 2019). Additionally,op managers are expected to have a strategic vision of supply chain 4.0 to make the right decisions of resource allocation and supply chain reconfiguration (Bienhaus and Haddud, 2018). A pivotalfactor related to management structure, human-resource strategy, working environment, and skills development for supply chain 4.0, is called human-resource and organizational skills (Frederico et al., 2019). As disruptive technologies require a set of new skills and continuous skill development, this practice should be embedded into the supply chain with a foresight and clear understanding of technology trends and respective skill requirements.

Blatz et al. (2018) states that the foundation for the integration is the availability of an infrastructure known as the "scaffolding structure" for the supply chain 4.0 development, implementation, and maintenance. Frederico et al. (2019) argues that without this "structure," it would be impossible to successfully implement supply chain 4.0.

Overall, the literature centers on the recommendation of supply chain 4.0 practices and an agreement on the benefits of integration in terms of cost reduction (Muthusami and Srinivsan, 2018), increased profitability (Tjahjono et al., 2017), efficient operating results (Wu et al., 2016) and customer satisfaction (Bukova et al., 2018).

2.4 SCQM

SCQM is a combination of SCM and QM, and it is the result of the evolution from an operational approach to a strategic approach (see Figure 2).

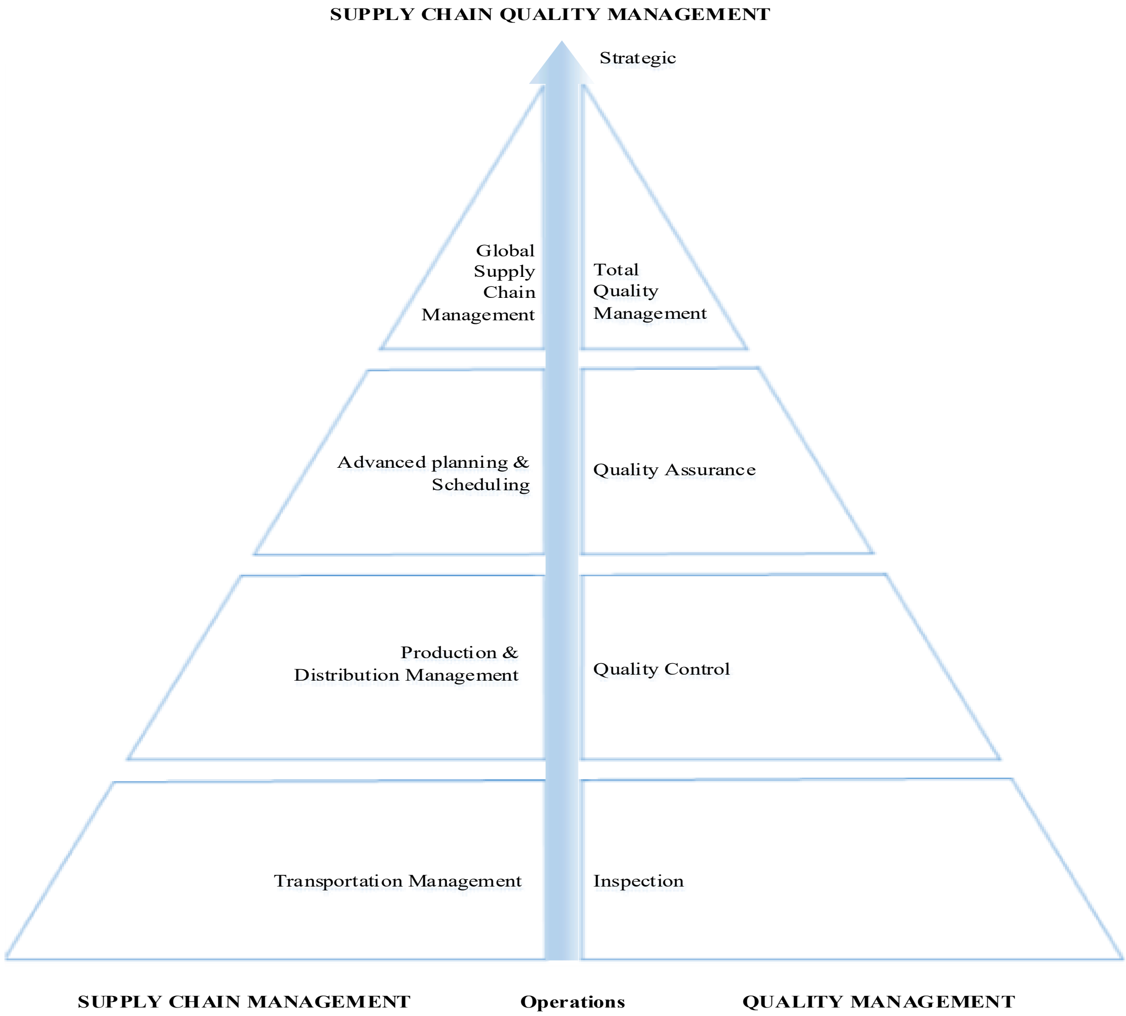

Figure 2 – Supply chain quality management

SCM's original research related to logistics was based on shipping management by developing containers and intermodal carriers. Subsequently, the concept of production and distribution management emerged through the consideration of warehousing, material handling, and freight, processes aided by advances in computers to optimize storage, inventory and truck routing. Finally, the emergence of enterprise resource planning (ERP) systems enabled the integration of multiple databases and improved data availability and accuracy for planning and integrating operations logistics action, known as advanced planning and scheduling. Today, SCM is associated with strategic issues related to current market globalization trends, such as coordinating complex supply networks due to global sourcing, making decisions about outsourcing or outsourcing, product recalls, social responsibility, etc (Cooper, Lambert, and Pagh 1997; Wieland, Handfield and Durach 2016; Cruz Trejos, Correa Espinal and Cogollo Florez 2012; Narasimhan, Venkatasubbaiah and Avadhani 2013).

SCM is another competitive source that supports companies to effectively handle concurrent global and challenging environments. Individual businesses cannot compete as independent entities but as active members of a broader supply chain, including a dense network of businesses and relationships (Lambert and Cooper 2000). Competitiveness can be achieved through operational efficiency and quality of service that will respond to challenges and manage opportunities across the entire supply chain.

At first, quality is attained by testing defects in products before being sent to the market. Thereafter, incremental quality control bypasses the error detection approach to evolve into a more systematic approach, in which statistical techniques are applied to solve quality problems. The concept of quality assurance has extended responsibility for quality to organizational functions towards strategic directions using more sophisticated statistical techniques (Arteaga Sierra et al. 2017). Total Quality Management (TQM) fulfils customer needs and enables quality to be a pervasive strategic issue in the organization, involving customers and suppliers. (Evans, Foster and Linderman 2014; Slack, Brandon-Jones and Johnston 2016; Cogollo-Florez and Correa-Espinal 2017; Zimon 2017).

QM is a quality-centric management approach of an organization, based on the engagements of all participants, and aimed at long-term success with customer satisfaction and the interests of both internal and external stakeholders.

QM has been adopted by many organizations as a key strategy for achieving competitive edges since the 1980s. QM ensures organizations to operate appropriately and effectively under the philosophy of "doing the job right" and "doing the right thing", "doing the right thing the first time" and "doing the right thing every time". However, fromthe outset, in order to meet customers' expectations in terms of product design and performance, QM needed to focus on the internal view of quality related to the management of the manufacturing process and products (Sousa and Voss 2002; MellatParast 2013).

With growing supply chain globalization and production decentralization, it is recognized that unleashing QM's potential requires equal attention to the upstream and downstream processes of the supply chain. (Zeng, Phan and Matsui 2013). Product quality depends on the quality processes from the manufacturers the suppliers (Fernandes et al. 2017) and the understanding of customer needs.

Thus, QM is an effective means of supporting SC operations by ensuring continuous performance improvement throughout SC, leading to higher levels of customer satisfaction. However, this requires that QM extend to both upstream and downstream processes instead of being limited to internal processes. Upstream QM initiatives include long-term relationships with suppliers, supplier involvement in product development and quality improvement, and supplier selection and certification focusing on quality. Downstream QM activities include regular meetings with customers, surveys to understand customer needs, seeking customer feedback on quality issues, and customer involvement in product design. Additionally, the seamless coordination of QM processes throughout the supply chain is even more important.

Supply Chain Quality Management (SCQM) is a recent development that supports the integration of SCM and QM. Robinson and Malhotra (2005) state that SCQM "is the formal coordination and integration of business processes engaging all partner organizations in the supply channel for measurement, analysis and continuous improvement products, services and processes to generate value and achieve ultimate customer satisfaction in the marketplace."

Generally, SCQM has been regarded as a systems-based approach to performance improvement that fosters synergy between best practices of SCM and QM to capitalize on opportunities created by upstream and downstream relationships with suppliers and customers (Foster Jr 2007). There is previous research revealing divergent opinions on SCQM. Ross (1998) was one of the first researchers to examine how all supply chain members participate in a supply chain, working together and committing to improving processes, products, services, and working culture to achieve total customer value and satisfaction.

Previous studies have highlighted a positive relationship between SCQM solutions and overall organizational performance (Wang et al. 2004, Kannan and Tan (2005), Lin et al. 2005; Azar, Kahnali and Taghavi 2010; Soares, Soltani and Liao 2017).

Wang et al. 2004 showed that quality improvement throughout the supply chain process leads to cost reduction, resource improvement, and process efficiency improvement.

Kannan and Tan (2005) confirm that there are relationships between supply chain management and quality management held by organizations at both the strategic and operational levels. Both organizational areas are part of their operational strategy, devoting to quality and understand that supply chain dynamics have the biggest impact on performance.

In general, the work has a consensus on the benefits of integration between SCM and QM solutions. Specifically, the lines of research emphasize the benefits of this integration. Previous studies have shown that QM can be utilised to improve the performance of the entire supply chain. However, froma quality management perspective, SCM can be recognized as providing quality products and services to all entities in the supply chain to live up to customer expectations. Since the objective of both QM and SCM is “customer satisfaction”, integration enhances the functionality of both, leading to increased organisational levels of customer satisfaction (Mahdiraji et al. events, 2012)Through the implementation of shared practices between QM and SCM such as leadership, information systems, management and strategic planning, stakeholder engagement and commitment, continuous improvement and innovation customary; organizational performance improved (Fernandes et al. 2017).

Based on the literature review performed, it is determined that there is a lack of research regarding integrating three aspects of SCQM: internal process, upstream QM, and downstream QM (Zeng et al. 2013) or an integrated methodology for managing all activities and relationships among all stakeholders of the supply chain.

2.5 SCQM4.0

With the Fourth Industrial Revolution, multiple disruptive technologies are of utmost significance to quality and performance improvement in supply chain operations (Ardito et al., 2019, Kothman and Faber, 2016, Lu, 2017, Nair et al., 2019, Oztemel and Gursev, 2020). Recently, many studies have been conducted to explore the relationship between these disruptive technologies and the quality or supply chain separately (Barata et al., 2018, Barreto et al., 2017, Bienhaus and Haddud, 2018, Bukova et al., 2018, Dallasega et al., 2018, Frederico et al., 2019, Hofmann and Rüsch, 2017, Kannan and Garad, 2020, Navas et al., 2020, Sony et al., 2020, Tjahjono et al., 2017). While there are numerous works in this area, the research addressed the integration of these technologies, quality, and supply chain management is limited as the unique impact of blockchain on supply chain quality management has been identified from the literature (Li et al., 2020, Chen et al., 2017). Table 2 presents a list of disruptive technologies upon which authors agree.

Table 2. List of disruptive technologies

Disruptive technologies	Authors
Web portals	(Ajam et al., 2010, Dallasega et al., 2018)
Management Information System (MIS)	(Zhou, 2008, Dallasega et al., 2018)
Global Positioning System (GPS)	(Shin et al., 2011, Young et al., 2010)

Ubiquitous Sensor Network (USN)	(Shin et al., 2011, Young et al., 2010)
Automated Materials Locating	(Shin et al., 2011, Young et al., 2010)
Tracking Technology (AMLTT)	(Shin et al., 2011, Young et al., 2010)
Building information modeling (BIM)	(London and Singh, 2013, Azambuja et al., 2012, Irizarry et al., 2013)
Embedded systems	(Tjahjono et al., 2017, Oztemel and Gursev, 2020)
Semantic machine-to-machine communication	(Barata et al., 2018, Bienhaus and Haddud, 2018, Tjahjono et al., 2017)
Cyber physical systems (CPS)	(Ardito et al., 2019, Barreto et al., 2017, Bienhaus and Haddud, 2018, Hofmann and Rüsch, 2017, Kache and Seuring, 2017, Muthusami and Srinivsan, 2018, Tjahjono et al., 2017, Tu, 2018)
Internet of things (IoT)	(Ardito et al., 2019, Barata et al., 2018, Barreto et al., 2017, Bienhaus and Haddud, 2018, Büyüközkan and Göçer, 2018, Iddris, 2018, Muthusami and Srinivsan, 2018, Tjahjono et al., 2017, Tu, 2018, Kannan and Garad, 2020, Navas et al., 2020)
Cloud technologies	(Ardito et al., 2019, Barata et al., 2018, Bienhaus and Haddud, 2018, Büyüközkan and Göçer, 2018, Hofmann and Rüsch, 2017, Tjahjono et al., 2017)
Big data analytics (BDA)	(Ardito et al., 2019, Büyüközkan and Göçer, 2018, Ghobakhloo, 2018, Hofmann and Rüsch, 2017, Iddris, 2018, Tjahjono et al., 2017) (Navas et al., 2020, Mazzuto and Ciarapica, 2019)
Radio frequency identification (RFID)	(Barata et al., 2018, Bienhaus and Haddud, 2018, Iddris, 2018, Tu, 2018, Wu et al., 2016, Navas et al., 2020)
Automatic identification and data collection (AIDC)	(Barreto et al., 2017, Büyüközkan and Göçer, 2018, Ghobakhloo, 2018, Hofmann and Rüsch, 2017, Tu, 2018, Wu et al., 2016)
Blockchain	(Li et al., 2020, Chen et al., 2017)
Robotics	(Büyüközkan and Göçer, 2018, Hofmann and Rüsch, 2017, Tjahjono et al., 2017, Kannan and Garad, 2020)
Augmented reality	(Barata et al., 2018, Büyüközkan and Göçer, 2018, Tjahjono et al., 2017)
Enterprise Resource Planning (ERP)	(Barata et al., 2018, Navas et al., 2020)
3D printing	(Büyüközkan and Göçer, 2018, Iddris, 2018, Tjahjono et al., 2017, Kannan and Garad, 2020)
Nanotechnology	(Büyüközkan and Göçer, 2018, Tjahjono et al., 2017)
Business intelligence	(Brinch, 2018a, Tjahjono et al., 2017)
Artificial Intelligence (AI)	(Bienhaus and Haddud, 2018, Muthusami and Srinivsan, 2018, Wu et al., 2016)

These new technologies would have implications for myriadbusiness areas, including R&D, quality improvement, supplier selection, production systems, smart factories, business analytics, etc., which will engender significant changes to supply chain quality management (Navas et al., 2020, Kannan and Garad, 2020, Soltanpoor and Sellis, 2016). Most of the authors have perceived these disruptive technologies ass an essential aspect of SCQM4.0 (Li et al., 2020, Chen et al., 2017). These techniques help increase transparency, integration, interoperability, performance, and collaboration across supply chain operations (Bukova et al., 2018, Dallasega et al., 2018, Sriram and Vinodh, 2020, Swanson, 2017). Moreover, the system merging these optimal techniques lays a foundation for more efficient resource allocation, enhanced flexibility, and responsiveness to meet customer needs (Brinch, 2018b, Bukova et al., 2018, Haddud et al., 2017, Wang et al., 2016).

The effectiveness of these techniques will be assessed through the supply chain processes (Frederico et al., 2019). In order to measure process performance, existing processes should be modelled (Quang and Hara, 2019). Process models describe supply chain activities from an information processing perspective (Quang and Hara, 2019). Process modelling can be described as descriptive and used as an interface for information systems development (Quang and Hara, 2019). For supply chain process modelling, there are several common approaches:

- Architecture of Information Systems (ARIS)
- Unified Modeling Language (UML)
- Integration Definition for Function Modeling (IDEF)
- Supply Chain Operations Reference (SCOR)

These approaches aim to describe processes, structures, and graphically depict entities that incorporate different planning horizons (Ivanov et al., 2017). In this study, the SCOR model was chosen as it allows elements to be divided into different hierarchical levels to facilitate detailed analysis in a structured manner. This makes its use in various fields intuitive, shedding light on its widespread use in academics and industry. Note that this SCOR model has been recognized as a well-known model for describing supply chain processes and measuring their performance (Ivanov et al., 2017).

The SCOR model describes the planning, sourcing, making, delivery, and return processes in the supply chain at various levels of abstraction. In addition, a consistent system of performance measurements is linked to the process model. As mentioned, the potential outcomes of SCOR processes are the impetus for disruptive technologies. The adoption of disruptive technologies, for example, leads to two problems: *interoperability* among technologies and *collaboration* between technologies and systems. This interoperability and collaboration will significantly impact the efficiency and effectiveness of the SCOR process (Grilo et al., 2013), facilitating the *integration* between supply chain actors. In vertical integration, techniques such as ERP and SAP are the key to combine functions in the company. The horizontal integration across the entire supply chain can be achieved through Big Data Analytics, Cloud Technologies, the Internet of Things, etc. The integration and collaboration support to accurately identify and capture data from all links in the supply chain, i.e. the ability to display and communicate that information, both internally and externally, at the level of detail required or desired, i.e. disclosure.

A blockchain-based supply chain quality management system along with the Internet of Things, Cyber-physical systems, and Semantic machine-to-machine communication, makes the supply chain more *transparent.* Since transparency encourages proactive behavior in supply chain actors by enabling them to identify and respond to various changes and customer needs. It, therefore, increases the responsiveness and flexibility of the supply chain processes. Furthermore, the system information sharing about upstream and downstream operations, allowing for more efficient resource allocation. Real-time sharing of raw material information helps customers confirm supplier quality issues, reduce return rates, and increase *process performance*.

Table 3. Description of Supply Chain Quality Management 4.0 constructs

SCQM4.0 constructs	Description	Authors
Infrastructure Practices		
Top management support	Degree to which top management understands the importance of the SCQM4.0 and the extent to which top management is willing to support the implementation of disruptive technologies to improve quality in the supply chain.	(Sriram and Vinodh, 2020, Stentoft et al., 2019, Nair et al., 2019, Bienhaus and Haddud, 2018, Iddris, 2018, Kache and Seuring, 2017)
IT Infrastructure	IT capabilities and resources should be made available for the initial development, implementation and the ongoing management and evolution of the disruptive technologies	(Sriram and Vinodh, 2020, Blatz et al., 2018)
Human resource skills	Management structure, human resource strategy, work environment and skill development for SCQM4.0, especially for adoption of new technologies	(Kannan and Garad, 2020, Frederico et al., 2019)
Coordination	Effective communication across the various tiers of the supply chain with full consideration of the evolutionary implications of SCQM4.0	(Sony et al., 2020, Frederico et al., 2019)
Organizational culture	A set of norms, beliefs and values shared by members of the organization towards SCQM4.0 understanding	(Sony et al., 2020, Frederico et al., 2019)
Awareness	A clear understanding among all entities in the supply chain regarding the benefits and requirements of the SCQM4.0	(Sony et al., 2020, Frederico et al., 2019)
Leadership	A clear insight into the evolutionary nature and strategic implications of SCQM4.0 to make the right decisions with regards to budget and resource allocations	(Sony et al., 2020, Frederico et al., 2019)
Core Elements		

Disruptive technologies	Refer to Table 2	
Interoperability	The ability of technologies to exchange and make use of information	(Sriram and Vinodh, 2020, Lu, 2017)
Collaboration	The extent to which information sharing among technologies and systems to create mutual benefits and accomplish goals including reducing cost and risk as well as improving quality and market value	(Sriram and Vinodh, 2020, Blatz et al., 2018)
Integration	Information and communication systems of all stakeholders are able to exchange information continuously through all planning, execution and completion of transportation and logistics activities throughout a product's life time	(Bukova et al., 2018, Swanson, 2017)
Transparency	Extent to which accurately identifying and collecting data from all links in the supply chain, i.e. visibility and communication that information, both internally and externally, at the level of detail required or desire	(Frederico et al., 2019)
Performance measurement	Effective measurement of processes in the SCOR model through the perfect order rate, defect rate or return rate	(Frederico et al., 2019, Dallasega et al., 2018)

The most complex and challenging when implementing SCQM4.0 is that the significant changes that need to be made in the organizational structure and business processes may face resistance from different supply chain stakeholders (Haddud et al., 2017, Kache and Seuring, 2017, Li et al., 2020). Dedication from top management can facilitate these changes (Ennis et al., 2018). Transparent and clear top management support will encourage all entities in the supply chain to beware of the benefits and requirements of SCQM4.0. Thus, the formation of an organizational culture shared by the chain members towards implementing SCQM4.0 and smooth coordination implies effective communication across different levels of the supply chain to conduct the SCQM4.0 strategy adequately. The success of SCQM4.0 also depends on incorporating SCQM4.0 technologies into business strategies. Supportive top management will help in the technology adoption process between the supply chain elements (Vendrell-Herrero et al., 2017).

SCQM4.0 uses many disruptive technologies to improve quality in the supply chain. IIT infrastructure is required for the initial deployment, development, management, and evolution of disruptive technologies (Sriram and Vinodh, 2020, Blatz et al., 2018). To implement SCQM4.0 technologies effectively, employees need to receive ongoing training in a strategic way (Kannan and Garad, 2020). The required SCQM4.0 skills, including technical aspects and transformational skills such as adaptability, critical thinking, creativity, teamwork, and knowledge transfer, must be updated continuously in terms of g technology transformation (Kannan and Garad, 2020). Instead of a transformational leadership style that limits idealistic influence, inspirational motivation, intellectual stimulation, and vision provision (Sony et al., 2020), SCQM4.0 is more demanding on the learning and innovation components.

This inquiry can be found in the knowledge-oriented leadership style, which is a combination of transformational and transactional leadership (Sony et al., 2020). Essentially, knowledge-oriented leadership is more specific to learning and innovation. However, it is still possible to extend the structure of this leadership style that will be used in SCQM4.0 by incorporating innovative role models, stimulating knowledge diffusion, supportive behaviors, delegation, consulting and mentoring, to build a SCQM4.0-driven leadership. Figure 3 describes supply chain quality management 4.0 constructs.

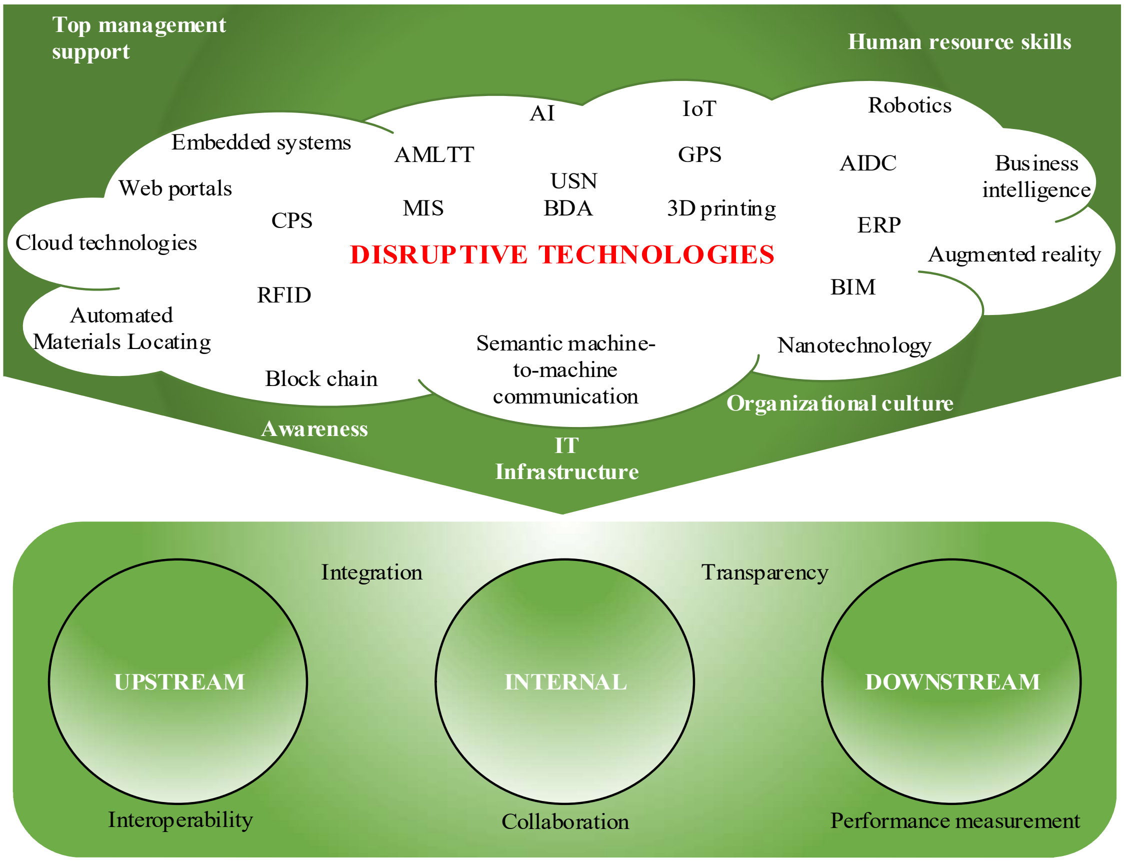

Figure 3 - SCQM4.0 theoretical framework

3. CONCLUSIONS AND FUTURE RESEARCH

With the development of Industries 4.0, disruptive technologies have increased rapidly. Technology 4.0 has created business ecosystems, improving quality and performance in supply chain operations. In academia, given that there are various works in this field, we found the integration research on all three concepts (Industries 4.0, Quality management and Supply chain management) is limited as the unique impact of blockchain, and the Internet of things on supply chain quality management or traceability was identified from two articles.

After a thorough review of historical developments and existing integration trends among Industries 4.0, quality and supply chain approaches along with future research directions outlined in the main literature, the emergence of a new research area - Supply Chain Quality Management 4.0 (SCQM4.0) is foreseen. This emerging field of research is expected to expand on the strengths, synergies, and established relationships between technologies 4.0, quality, and supply chain, contributing towards a pioneering and quality supply chain.

Not only introduce the term SCQM4.0 and propose a definition for it, but this article also contributed a new conceptual SCQM4.0 framework. Stemming from the gaps, opportunities, and benefits identified in the literature, the SCQM4.0 conceptual framework builds on the high potential of SCQM4.0 constructs to achieve successful governance and implementation. The proposed bottom-up cause-and-effect relationship between works within the framework can be considered a "road map" for SCQM4.0 implementations. Indeed, an organization will achieve perfection in supply chain management and elevate the company in the marketplace if it can locate and scope the approaches in the SCQM4.0 roadmap. The company will know exactly what needs to be added or modified to complete the procedure. Industry practitioners are encouraged to perform gap analysis and direct the implementation of the strategy to establish an excellent SCQM4.0.

The proposed SCQM4.0 framework makes relevant and significant contributions to the academic community. The follow-up exploratory studies should be carried out in different organizations to explore additional key constructs specific to a sector. In doing so, a measurement scale of these SCQM4.0 constructs needs to be developed and tested, after which it is imperative to validate the proposed SCQM4.0 model with the hypothesis of the bottom-up cause-and-effect proposition. As SCQM4.0 is still in its infancy, empirical research such as case studies or surveys can be useful to develop a more comprehensive set of SCQM4.0 dimensions. Various geographical regions, business sectors and different sized organizations are recommended to be probed for validating the relationships identified in this article. It prefers that the application of mixed methods, i.e. qualitative and quantitative methods, is particularly promoted, on the basis of obtaining more valid and reliable insights using such methods on integration research. Furthermore, the SCQM4.0 framework depicts a general picture, which means that empirical research for detailed segments of SCQM4.0 is beneficial to provide insight into specific areas under investigation.

There are advantages and disadvantages that a company will accumulate by embarking on SCQM4.0. Upcoming in-depth interviews with CEOs to explore these benefits and limitations play a part in supporting such companies, backing efforts on the path to successful SCQM4.0 strategy implementation.

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References

Ajam, M., Alshawi, M. and Mezher, T. (2010), "Augmented process model for e-tendering: Towards integrating object models with document management systems", *Automation in Construction,* Vol. 19 No. 6, pp. 762-778.

Alfian, G., Syafrudin, M. and Rhee, J. (2017), "Real-time monitoring system using smartphone-based sensors and nosql database for perishable supply chain", *Sustainability,* Vol. 9 No. 11, p. 2073.

Androulaki, E., Barger, A., Bortnikov, V., Cachin, C., Christidis, K., De Caro, A., Enyeart, D., Ferris, C., Laventman, G. and Manevich, Y. (2018), "Hyperledger fabric: a distributed operating system for permissioned blockchains", in *Proceedings of the thirteenth EuroSys conference*, pp. 1-15.

Ardito, L., Petruzzelli, A. M., Panniello, U. and Garavelli, A. C. (2019), "Towards Industry 4.0: Mapping digital technologies for supply chain management-marketing integration", *Business Process Management Journal*.

Aung, M. M. and Chang, Y. S. (2014a), "Traceability in a food supply chain: Safety and quality perspectives", *Food Control,* Vol. 39 No. 0, pp. 172-184.

Aung, M. M. and Chang, Y. S. (2014b), "Traceability in a food supply chain: Safety and quality perspectives", *Food control,* Vol. 39, pp. 172-184.

Azambuja, M., Alves, T., Leite, F. and Gong, J. (2012), "Leveraging building information models to support supply chain decisions in construction projects", in *Construction Research Congress 2012: Construction Challenges in a Flat World*, pp. 747-756.

Baker, P. (2008), "The design and operation of distribution centres within agile supply chains", *International Journal of Production Economics,* Vol. 111 No. 1, pp. 27-41.

Barata, J., Da Cunha, P. R. and Stal, J. (2018), "Mobile supply chain management in the Industry 4.0 era: An annotated bibliography and guide for future research", *Journal of Enterprise Information Management*.

Barnett-Page, E. and Thomas, J. (2009), "Methods for the synthesis of qualitative research: a critical review", *BMC medical research methodology,* Vol. 9 No. 1, pp. 1-11.

Barreto, L., Amaral, A. and Pereira, T. (2017), "Industry 4.0 implications in logistics: an overview", *Procedia Manufacturing,* Vol. 13, pp. 1245-1252.

Ben-Daya, M., Hassini, E., Bahroun, Z. and Banimfreg, B. H. (2020), "The role of internet of things in food supply chain quality management: A review", *Quality Management Journal,* Vol. 28 No. 1, pp. 17-40.

Bienhaus, F. and Haddud, A. (2018), "Procurement 4.0: factors influencing the digitization of procurement and supply chains", *Business Process Management Journal*.

Blatz, F., Bulander, R. and Dietel, M. (2018), "Maturity model of digitization for SMEs", in *2018 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC)*, pp. 1-9.

Brinch, M. (2018a), "Understanding the value of big data in supply chain management and its business processes", *International Journal of Operations & Production Management*.

Brinch, M. (2018b), "Understanding the value of big data in supply chain management and its business processes: Towards a conceptual framework", *International Journal of Operations & Production Management*.

Briner, R. B. and Denyer, D. (2012), "Systematic review and evidence synthesis as a practice and scholarship tool", *Handbook of evidence-based management: Companies, classrooms and research*, pp. 112-129.

Bukova, B., Brumercikova, E., Cerna, L. and Drozdziel, P. (2018), "The position of Industry 4.0 in the worldwide logistics chains", *LOGI–Scientific Journal on Transport and Logistics,* Vol. 9 No. 1, pp. 18-23.

Büyüközkan, G. and Göçer, F. (2018), "Digital supply chain: literature review and a proposed framework for future research", *Computers in Industry,* Vol. 97, pp. 157-177.

Chen, K. and Xiao, T. (2015), "Outsourcing strategy and production disruption of supply chain with demand and capacity allocation uncertainties", *International Journal of Production Economics,* Vol. 170, pp. 243-257.

Chen, S., Shi, R., Ren, Z., Yan, J., Shi, Y. and Zhang, J. (2017), "A blockchain-based supply chain quality management framework", in *2017 IEEE 14th International Conference on e-Business Engineering (ICEBE)*, pp. 172-176.

Chenga, J. (2011), "A web service framework for measuring and monitoring environmental and carbon footprint in construction supply chains", *Procedia Engineering,* Vol. 14, pp. 141-147.

Chopra, S. and Sodhi, M. (2012), "Managing risk to avoid supply-chain breakdown", *MIT Sloan Management Review (Fall 2004),* Vol. 46 No. 1, pp. 53-61.

Chou, C.-H., Shrestha, S., Yang, C.-D., Chang, N.-W., Lin, Y.-L., Liao, K.-W., Huang, W.-C., Sun, T.-H., Tu, S.-J. and Lee, W.-H. (2018), "miRTarBase update 2018: a resource for experimentally validated microRNA-target interactions", *Nucleic acids research,* Vol. 46 No. D1, pp. D296-D302.

Cui, L., Wang, L. and Deng, J. (2014), "RFID technology investment evaluation model for the stochastic joint replenishment and delivery problem", *Expert Systems with Applications,* Vol. 41 No. 4, Part 2, pp. 1792-1805.

Dabbene, F., Gay, P. and Tortia, C. "Traceability issues in food supply chain management: A review", *Biosystems Engineering,* No. 0.

Dallasega, P., Rauch, E. and Linder, C. (2018), "Industry 4.0 as an enabler of proximity for construction supply chains: A systematic literature review", *Computers in industry,* Vol. 99, pp. 205-225.

Das, M., Cheng, J. C. and Law, K. H. (2015), "An ontology-based web service framework for construction supply chain collaboration and management", *Engineering, Construction and Architectural Management.*

Dike, I. U. and Kapogiannis, G. (2014), "A conceptual model for improving construction supply chain performance", in *Proceedings of the 30th Annual Association of Researchers in Construction Management Conference (ARCOM 2014), Portsmouth, UK*, pp. 14-19.

Ennis, C., Barnett, N., De Cesare, S. and Lander, R. (2018), "A conceptual framework for servitization in Industry 4.0: Distilling directions for future research", *Ennis, C., Barnett, N.,* *De Cesare, S., Lander, R. and Pilkington, A.(2018). A Conceptual Framework for Servitization in Industry,* Vol. 4.

Ergen, E., Demiralp, G. and Guven, G. (2011), "Determining the benefits of an RFID-based system for tracking pre-fabricated components in a supply chain", *Computing in Civil Engineering (2011)*, pp. 291-298.

Fernandes, A. C., Sampaio, P., Sameiro, M. and Truong, H. Q. (2017), "Supply chain management and quality management integration: A conceptual model proposal", *International Journal of quality & reliability management,* Vol. 34 No. 1, pp. 53-67.

Frederico, G. F., Garza-Reyes, J. A., Anosike, A. and Kumar, V. (2019), "Supply Chain 4.0: concepts, maturity and research agenda", *Supply Chain Management: An International Journal*.

Getuli, V., Ventura, S. M., Capone, P. and Ciribini, A. L. (2016), "A BIM-based construction supply chain framework for monitoring progress and coordination of site activities", *Procedia engineering,* Vol. 164, pp. 542-549.

Ghobakhloo, M. (2018), "The future of manufacturing industry: a strategic roadmap toward Industry 4.0", *Journal of Manufacturing Technology Management*.

Grilo, A., Zutshi, A., Jardim-Goncalves, R. and Steiger-Garcao, A. (2013), "Construction collaborative networks: the case study of a building information modelling-based office building project", *International Journal of Computer Integrated Manufacturing,* Vol. 26 No. 1-2, pp. 152-165.

Haddud, A., DeSouza, A., Khare, A. and Lee, H. (2017), "Examining potential benefits and challenges associated with the Internet of Things integration in supply chains", *Journal of Manufacturing Technology Management*.

Hofmann, E. and Rüsch, M. (2017), "Industry 4.0 and the current status as well as future prospects on logistics", *Computers in industry,* Vol. 89, pp. 23-34.

Iddris, F. (2018), "Digital supply chain: survey of the literature", *International Journal of Business Research and Management,* Vol. 9 No. 1, pp. 47-61.

Irizarry, J., Karan, E. P. and Jalaei, F. (2013), "Integrating BIM and GIS to improve the visual monitoring of construction supply chain management", *Automation in construction,* Vol. 31, pp. 241-254.

Ivanov, D., Tsipoulanidis, A. and Schönberger, J. (2017), "Global supply chain and operations management", *A decision-oriented introduction to the creation of value,* Vol. 2.

Kache, F. and Seuring, S. (2017), "Challenges and opportunities of digital information at the intersection of Big Data Analytics and supply chain management", *International Journal of Operations & Production Management*.

Kannan, K. S. P. and Garad, A. (2020), "Competencies of quality professionals in the era of industry 4.0: a case study of electronics manufacturer from Malaysia", *International Journal of Quality & Reliability Management*.

Kaplan, R. S. and Norton, D. (1992), "The Balanced Scorecard: Measures that Drive Performance", *Harvard Business Review,* Vol. 70 No. 1, pp. 71–79.

Kitchenham, B. (2004), "Procedures for performing systematic reviews", *Keele, UK, Keele University,* Vol. 33 No. 2004, pp. 1-26.

Kothman, I. and Faber, N. (2016), "How 3D printing technology changes the rules of the game: Insights from the construction sector", *Journal of Manufacturing Technology Management*.

Li, J., Maiti, A., Springer, M. and Gray, T. (2020), "Blockchain for supply chain quality management: challenges and opportunities in context of open manufacturing and industrial internet of things", *International Journal of Computer Integrated Manufacturing,* Vol. 33 No. 12, pp. 1321-1355.

London, K. and Singh, V. (2013), "Integrated construction supply chain design and delivery solutions", *Architectural engineering and design management,* Vol. 9 No. 3, pp. 135-157.

Lu, Y. (2017), "Industry 4.0: A survey on technologies, applications and open research issues", *Journal of industrial information integration,* Vol. 6, pp. 1-10.

Luo, Y., Benali, A., Shulenburger, L., Krogel, J. T., Heinonen, O. and Kent, P. R. (2016), "Phase stability of TiO2 polymorphs from diffusion quantum Monte Carlo", *New Journal of Physics,* Vol. 18 No. 11, p. 113049.

Mazzuto, G. and Ciarapica, F. E. (2019), "A big data analytics approach to quality, reliability and risk management", *International Journal of Quality & Reliability Management*.

Muthusami, S. and Srinivsan, M. (2018), "Supply chain 4.0: digital transformation, disruptions and strategies", *Review of Business and Technology Research,* Vol. 14 No. 2, pp. 32-35.

Nair, J., Chellasamy, A. and Singh, B. B. (2019), "Readiness factors for information technology adoption in SMEs: testing an exploratory model in an Indian context", *Journal of Asia Business Studies*.

Navas, M. A., Sancho, C. and Carpio, J. (2020), "Disruptive maintenance engineering 4.0", *International Journal of Quality & Reliability Management*.

Oztemel, E. and Gursev, S. (2020), "Literature review of Industry 4.0 and related technologies", *Journal of Intelligent Manufacturing,* Vol. 31 No. 1, pp. 127-182.

Pang, A. L., Ismail, H. and Bakar, A. A. (2015), "Effects of kenaf loading on processability and properties of linear low-density polyethylene/poly (vinyl alcohol)/kenaf composites", *BioResources,* Vol. 10 No. 4, pp. 7302-7314.

Quang, H. T. and Hara, Y. (2019), "Managing risks and system performance in supply network: a conceptual framework", *International Journal of Logistics Systems and Management,* Vol. 32 No. 2, pp. 245-271.

Quang, H. T., Sampaio, P., Carvalho, M. S., Fernandes, A. C., An, D. T. B. and Vilhenac, E. (2016), "An extensive structural model of supply chain quality management and firm performance", *International Journal of Quality & Reliability Management,* Vol. 33 No. 4, pp. 444-464.

Robertson, G. R., Field, J., Goodwin, B., Bierach, S., Tran, M., Lehnert, A. and Liddle, C. (2003), "Transgenic mouse models of human CYP3A4 gene regulation", *Molecular pharmacology,* Vol. 64 No. 1, pp. 42-50.

Seifert, B., d'Eustacchio, D., Kaufmann, B., Centorame, M., Lorite, P. and Modica, M. (2017), "Four species within the supercolonial ants of the Tapinoma nigerrimum complex revealed by integrative taxonomy (Hymenoptera: Formicidae)", *Myrmecological News,* Vol. 24, pp. 123-144.

Shi, H., Pu, J., Zhou, X.-L., Ning, Y.-Y. and Bai, C. (2017), "Silencing long non-coding RNA ROR improves sensitivity of non-small-cell lung cancer to cisplatin resistance by inhibiting PI3K/Akt/mTOR signaling pathway", *Tumor Biology,* Vol. 39 No. 5, p. 1010428317697568.

Shin, T.-H., Chin, S., Yoon, S.-W. and Kwon, S.-W. (2011), "A service-oriented integrated information framework for RFID/WSN-based intelligent construction supply chain management", *Automation in Construction,* Vol. 20 No. 6, pp. 706-715.

Soltanpoor, R. and Sellis, T. (2016), "Prescriptive analytics for big data", in *Australasian database conference*, pp. 245-256.

Sony, M. (2018), "Industry 4.0 and lean management: a proposed integration model and research propositions", *Production & Manufacturing Research,* Vol. 6 No. 1, pp. 416-432.

Sony, M., Antony, J. and Douglas, J. A. (2020), "Essential ingredients for the implementation of Quality 4.0: A narrative review of literature and future directions for research", *The TQM Journal*.

Sriram, R. and Vinodh, S. (2020), "Analysis of readiness factors for Industry 4.0 implementation in SMEs using COPRAS", *International Journal of Quality & Reliability Management*.

Stentoft, J., Jensen, K. W., Philipsen, K. and Haug, A. (2019), "Drivers and barriers for Industry 4.0 readiness and practice: a SME perspective with empirical evidence", in *Proceedings of the 52nd Hawaii International Conference on System Sciences*.

Stock, T. and Seliger, G. (2016), "Opportunities of sustainable manufacturing in industry 4.0", *Procedia Cirp,* Vol. 40, pp. 536-541.

Swanson, D. (2017), "The impact of digitization on product offerings: using direct digital manufacturing in the supply chain", in *Proceedings of the 50th Hawaii International Conference on System Sciences*.

Tang, L., Cho, S. and Xia, L. (2013), "Intelligent BVAC information capturing system for smart building information modelling", in *2013 5th International Conference on Power Electronics Systems and Applications (PESA)*, pp. 1-4.

Thomas, J. and Harden, A. (2008), "Methods for the thematic synthesis of qualitative research in systematic reviews", *BMC medical research methodology,* Vol. 8 No. 1, pp. 1-10.

Tian, F. (2016), "An agri-food supply chain traceability system for China based on RFID & blockchain technology", in *2016 13th international conference on service systems and service management (ICSSSM)*, pp. 1-6.

Tjahjono, B., Esplugues, C., Ares, E. and Pelaez, G. (2017), "What does industry 4.0 mean to supply chain?", *Procedia manufacturing,* Vol. 13, pp. 1175-1182.

Tripoli, M. and Schmidhuber, J. (2018), "Emerging Opportunities for the Application of Blockchain in the Agri-food Industry", *FAO and ICTSD: Rome and Geneva. Licence: CC BY-NC-SA,* Vol. 3.

Truong, H. Q. and Hara, Y. (2018), "Supply chain risk management: manufacturing-and service-oriented firms", *Journal of Manufacturing Technology Management,* Vol. 29 No. 2, pp. 218-239.

Truong, H. Q., Sameiro, M., Fernandes, A. C., Sampaio, P. and Duong, B. A. T. (2017), "Supply chain management practices and firms' operational performance", *International Journal of Quality & Reliability Management,* Vol. 34 No. 2, pp. 176-193.

Tsang, S., Royse, C. F. and Terkawi, A. S. (2017), "Guidelines for developing, translating, and validating a questionnaire in perioperative and pain medicine", *Saudi journal of anaesthesia,* Vol. 11 No. Suppl 1, p. S80.

Tu, M. (2018), "An exploratory study of Internet of Things (IoT) adoption intention in logistics and supply chain management", *The International Journal of Logistics Management*.

Vendrell-Herrero, F., Bustinza, O. F., Parry, G. and Georgantzis, N. (2017), "Servitization, digitization and supply chain interdependency", *Industrial Marketing Management,* Vol. 60, pp. 69-81.

Vos, T., Barber, R. M., Bell, B., Bertozzi-Villa, A., Biryukov, S., Bolliger, I., Charlson, F., Davis, A., Degenhardt, L. and Dicker, D. (2015), "Global, regional, and national incidence, prevalence, and years lived with disability for 301 acute and chronic diseases and injuries in 188 countries, 1990–2013: a systematic analysis for the Global Burden of Disease Study 2013", *The lancet,* Vol. 386 No. 9995, pp. 743-800.

Wang, G., Gunasekaran, A., Ngai, E. W. and Papadopoulos, T. (2016), "Big data analytics in logistics and supply chain management: Certain investigations for research and applications", *International Journal of Production Economics,* Vol. 176, pp. 98-110.

Wang, M., Audi, G., Kondev, F., Huang, W., Naimi, S. and Xu, X. (2017a), "The AME2016 atomic mass evaluation", *Chin. Phys. C,* Vol. 41, p. 030003.

Wang, P., Zhang, X., Zhang, J., Wan, S., Guo, S., Lu, G., Yao, J. and Huang, X. (2017b), "Precise tuning in platinum-nickel/nickel sulfide interface nanowires for synergistic hydrogen evolution catalysis", *Nature communications,* Vol. 8 No. 1, pp. 1-9.

Webster, J. and Watson, R. T. (2002), "Analyzing the past to prepare for the future: Writing a literature review", *MIS quarterly*, pp. xiii-xxiii.

Wu, L., Yue, X., Jin, A. and Yen, D. C. (2016), "Smart supply chain management: a review and implications for future research", *The International Journal of Logistics Management*.

Yang, C. H., Wu, T.-H., Chiou, Y.-Y., Hung, S.-C., Lin, C.-J., Chen, Y.-C., Sheu, M.-H., Guo, W.-Y. and Chiu, C. F. "Imaging Quality and Diagnostic Reliability of Low Dose CT Lumbar Spine for Evaluating Patients with Spinal Disorders", *The Spine Journal,* No. 0.

Young, D., Nasir, H., Razavi, S., Haas, C., Goodrum, P. and Caldas, C. (2010), "Automated materials tracking and locating: impact modeling and estimation", in *Construction Research Congress 2010: Innovation for Reshaping Construction Practice*, pp. 41-50.

Zheng, S., Li, X., Yan, B., Hu, Q., Xu, Y., Xiao, X., Xue, H. and Pang, H. (2017), "Transition-metal (Fe, Co, Ni) based metal-organic frameworks for electrochemical energy storage", *Advanced Energy Materials,* Vol. 7 No. 18, p. 1602733.

Zhou, J. (2008), "The optimization mode for construction supply chain management based on information techniques", in *2008 IEEE International Conference on Service Operations and Logistics, and Informatics*, Vol. 1, pp. 1054-1058.

DIRECT AND INDIRECT EFFECTS OF RISKS ON SERVICE-ORIENTED SUPPLY CHAIN: A COVID-19 PANDEMIC PERSPECTIVE

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STRUCTURED ABSTRACT

Purpose - A solid service-oriented foundation is required to make supply chain management a competitive advantage, especially in this Covid-19 pandemic. A well-established service-oriented supply chain becomes more adaptable to changing client expectations. This study aims at analysing the direct and indirect impact of risks on the service-oriented supply chain from a pandemic perspective.

Design/methodology/approach - The Q-sort method is applied with the participation of nine top-level managers to initially review the reliability, validity, and unidimensionality of research concepts. Then a questionnaire containing these measuring variables is developed to obtain the opinions of those who are experienced in logistics and supply chain management. These empirical data are analysed based on Structural Equation Modelling (SEM) to evaluate direct and indirect effects of risks on supply chain performance.

Findings - The risk is inherent in service-oriented supply chains, affecting both direct and indirect performance. The proposed risk model explains 33.6 percent of Supplier performance, 46.4 percent of Operational performance, 47.1 percent of Customer satisfaction, and 46.5 percent of Finance variation. We found that service-oriented supply chains effectively monitor demand risk. External risk has the smallest impact on supply chain performance measures, whereas demand risk has the smallest effect. That a service-oriented supply chain is focused on meeting customer demand and managing demand-related risks is reinforced by these findings.

Research limitations/implications - In the literature on supply chain risk management, resilience studies and disruption management receive less attention than studies on risk assessment and risk mitigation (Katsaliaki et al., 2021). Future supply chain risk management research should differentiate between risk-as an event and/or risk-as a process since they have different periodic effects on response management and resilience.

Originality/value - This is a pioneering study looking at the risk side of service-oriented supply chain. The data using in this research is from a large-scale survey supported by Japanese Government to promote ASEAN sustainable socio-economic development. This dataset collected during the Covid-19 pandemic to validate our models is an interesting and topical point of this study.

Keywords: Risk, Supply chain performance, Supply chain risk management, Service dominant logic**,** Service-oriented supply chain, Covid-19 pandemic.

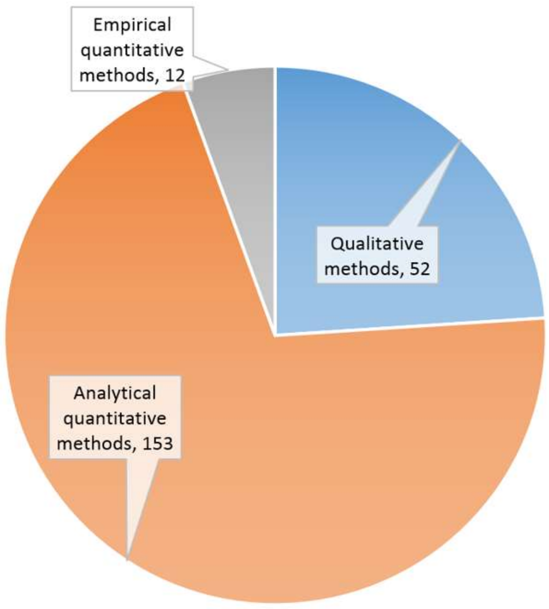
Paper type: Research paper.

1. Introduction

Queiroz et al. (2020) and Ivanov (2021) have pinpointed that the outbreak of Covid-19 pandemic has done a disservice to the economic climates of numerous nations and disrupted global supply chains. Additionally, the detriments of pandemic, according to IMF, prove more calamitous than the 1929 Great Depression.

The lack of clinical remedies and vaccinations exacerbate Covid-19 pandemic 's position. In response, the authorities imposed municipal lockdown and social distancing. The pandemic's direct and indirect effects on supply networks are notable (Roberton et al., 2020). Ivanov (2021) attributes supply chain management issues, labor shortages at internal business and logistics systems to the pandemic's spread and subsequent measures. The implementation of lockdown has impacted the workforce, global exports and imports, causing supply chain disruptions and supply-side shocks (Queiroz et al., 2020). The pandemic's impact on consumer behavior is seen in increased demand for online shopping and home services. Nonetheless, rising client demand has harmed the supply side (Ivanov, 2021). The pandemic's severe dangers impede manufacture (Ivanov, 2021; Queiroz et al., 2020).

Although both direct and indirect effects of risks on supply chains are undeniable (Vickery et al., 2003), little study has shed light on the influences of risks within the supply chain. Most supply chain risk research focuses on single relationships, qualitative research, or case studies, so current understanding is limited (Figure 1). Wagner and Bode (2008) claimed that large-scale empirical research' findings of inter-linkages across risks are scarce and primarily descriptive.



	Empirical quantitative methods	
Individual quantitative methods	Multiple regression model	3
	Partial least squares analysis	1
	Quantitative survey analysis	1
	Real options theory	1
	Statistical analysis	1
Integrated quantitative methods	Analytic hierarchy process; Survey; Wards ' and K-mean clustering; Nonparametric Spearman rank correlation test	1
	Survey, Bow-Tie analysis, and fuzzy inference system (FIS)	1
	Cluster analysis; Factor analysis	1
	Exploratory factor analysis; Regression models; Reliability tests	1
	Structural equation modelling technique; Partial least squares analysis	1

Figure 1 - Research methodologies in the supply chain risk literature (2003 – 2020)

This study will analyse the direct and indirect impact of risks on the service-oriented supply chain from a Covid-19 pandemic perspective. A service-oriented supply chain that centres around the customers is well positioned to deal with the pandemic's demand risks. According to Prasetyanti and Simatupang (2015), service-oriented supply chain is a combination of service science and supply chain theory. Service-dominant logic assumes the customer is important and should be included in the value creation process. By embedding this logic into the supply chain, a service-oriented supply network becomes more adaptable in the face of customer demands. We obtained data from the Vietnamese construction industry, one of the most affected by the pandemic (Gamil & Alhagar, 2020).

The remainder of this article is as follows. Risks in the service-oriented supply chain are modelled prior to evaluation with empirical data from the Vietnamese construction industry. The results are then discussed and topics for future research and conclusions are drawn up.

2. Theoretical background

2.1 Service-oriented supply chain

Inaction will stifle social growth; just as institutional logic has strangled scientific advancement. A new perspective is proposed to change the old in the realm of economic and social interchange between human actors, individually and collectively, and the supply chain. Initially, production was simple, with products moving from suppliers through producers to markets. Increasing demand has led to complex supply systems (Christopher & Peck, 2004a). Supply chain efficiency is threatened by changing consumer trends, particularly in Covid-19 pandemic. Quang and Hara (2019) say that evolving client demands, new technology, firm growth, and structural changes propel service-oriented supply chains forward. Online shopping, home delivery, and other emerging trends during the pandemic demonstrate that people prefer services to buying stuff. As a result, a more robust service-oriented supply chain is a possible solution.

The introduction of service science into supply chain theory is a service-oriented supply chain, where the customer is the centre of processes (Prasetyanti & Simatupang, 2015). Wu and Wu (2015) discovered this integration and suggested that supply chain and service science have many similarities and may complement each other. For example:

- A supply chain is a series of interconnected enterprises that must have a strong-oriented base in order to satisfy customer needs.
- Each member in the supply chain serves as both a customer and a supplier and performs value-added activities on products. A dual-sided role's success necessitates information sharing between parties.

Service-Dominant Logic is a novel marketing concept that evaluates goods and services based on their ability to meet customer demands (Vargo & Lusch, 2004). An argument supporting the suitability of partnership and relationship-based approaches to the aforementioned concerns (Vargo & Lusch, 2004). To generate value, service-dominant thinking must incorporate the client. In this service science model, customers co-create value, transforming the supply chain into a value-creation network, or value constellation, as follows:

> *[…] naturally perceiving and responding spatial and temporal structure of largely loosely coupled value, proposing social and economic actors to interact through institutions and technologies to: coproduce service offerings; exchange service offering; co-create value (Lusch, 2011).*

The value can only be created through value co-creation which is a beneficial interaction between customers and supply chain stakeholders. Meanwhile, the contact is the result of a chain of linked value activities that present a value for meeting consumer expectations. Therefore, the supply chain should be regarded as a service ecosystem (Flint et al., 2014).

Facility design, inventory management, shipping and distribution rules, sourcing activities, and price decisions, are not ignored in a service-oriented supply chain (Prasetyanti & Simatupang, 2015). Therefore, risks in a service-oriented supply chain are all-encompassing and intertwined.

2.2 Supply chain risks

Risk treatment attitude varies depending on the firm/supply chain strategy (Quang & Hara, 2019; Wagner & Bode, 2008). Traditional strategic management research in supply chain risk management divides strategy into two dimensions: process and content. Several academics have studied method and/or content to identify supply chain vulnerabilities (Thun & Hoenig, 2011; Wagner & Bode, 2008). Despite the huge number of hazards described, Truong Quang and Hara (2018) hypothesized that internal and external supply chain aspects should be included in this framework.

This argument is supported by the contingency theory, whose central premise is that:

> *[…] high supply chain efficiency and business performance when supply chains consider the context in which strategy is formulated and executed (Wagner & Bode, 2008).*

As such, supply chains should match their structure with the context and environment, i.e., external pressures. "Opportunities are lost, costs rise, and supply chain maintenance is threatened" unless this "match" is reached (Child, 1972).

Duncan (1972) defines the environment as "the totality of physical and social elements that have an effect on supply chain performance." This concept encompasses both internal and external supply chain risk elements. Expanding the scope of risks, Wagner and Bode (2008) claimed that:

> *[…] Supply chain risk sources are critical contextual variables that can be internal and external to supply chains and to the aScting firms in a supply chain network.*

In line with this approach, Jüttner (2005) investigated risk not only at a company's processes, but also at supply chain flows from initial suppliers to end-user delivery. In empirical research of 67 German automotive companies, Thun and Hoenig (2011) found a considerable difference in the influence of internal and external supply chain risks on performance.

Because the authors classified hazards according to different levels of impact, Ho et al. (2015) provided a novel and more complete idea to this point of view. Supply chain risk was defined as "the likelihood and impact of unexpected macro and/or micro-level events or conditions that are detrimental to any part of a supply chain that results in failures or irregularities at the operational, tactical, or strategic level". From this approach, there are two forms of risk in a service-oriented supply chain (Figure 2):

- External risk is relatively rare and adverse external events or phenomena that may have strong impacts on supply chain performance (Thun & Hoenig, 2011).
- Internal risks are incidents that occur regularly and are caused by internal company operations or connections with supply chain network partners. They are more likely to occur than external supply chain hazards, although they have a lesser impact on performance (Thun & Hoenig, 2011).

Figure 2 - Risks on Service-Oriented Supply Chain

These various supply chain risk events are interrelated in intricate patterns, with one risk leading to another or influencing the outcome of other risks (Wagner & Bode, 2008). Although supply chains include such interconnections, the unpredictability and significance of these interconnections escalates in the pandemic.

External risk

Natural catastrophes, such as earthquakes and tsunamis; war and terrorism; diseases (Covid-19 pandemic), etc., can cause irreversible damage to a service-oriented supply chain (Ivanov, 2021; Quang & Hara, 2019; Queiroz et al., 2020; Shareef et al., 2020). To exemplify,

- On March 11, 2011, the Tōhoku earthquake and huge tsunami waves at Miyako, Tōhoku' Iwate Prefecture, Japan, are natural disaster repercussions. Although it was only 6 minutes, it caused a $360-billion-dollar economic loss (Fire and Disaster Management Agency, 2020).
- Hurricane Harvey, the costliest tropical storm on record with anticipated devastation of over 125 billion dollars, shuttering not only 11 percent of US oil refining capacity and 25% of oil output in the Gulf of Mexico, but also 90 percent of the country's capacity to create and ship base plastics.
- According to Hansen et al. (2013), an economic recession generates fluctuations in market demand, poor financial implications, a highly dynamic, complex operating business environment (Quang & Hara, 2018), and can even disrupt supplier-buyer ties (Krause & Ellram, 2014). In addition, having a multitude of procedures generates delays, difficulties in transactions among supply chain members, and capital access (Dreher & Gassebner, 2013).
- Different local cultures, languages, and politics are another hurdle for service-oriented businesses (Quang & Hara, 2019). Inconsistencies can lead to miscommunications, which can stifle a service-oriented supply chain. For example, Airbus lost 4.8 billion Euros owing to a two-year delay in introducing the A38. The political pressure to "fulfil" the expectations of four diverse European nations could cause the delay, aside from technical concerns. Cultural variations can also impact corporate procedures like demand forecasting and material planning (Quang & Hara, 2019).
- The recent Covid-19 pandemic has aroused researchers' and clinicians' interest. This pandemic has caused an economic shock, with over 170 countries experiencing negative GDP growth per capita (IMF, 2020). Due to the lack of a vaccine, efficient treatments, and non-pharmaceutical measures, supply chain management and logistics systems face major supply and demand challenges (Ivanov, 2021; Queiroz et al., 2020). Economic growth and financial stability have been hampered by social distancing, according to Barichello (2020).

External risks apparently affect internal supply chain risks and service-oriented supply chain performance. Therefore, here are our proposal of several hypotheses:

H1: External risk adversely affects Supply risk (H1a), Operational risk (H1b), Demand risks (H1c), and Finance (H1d).

Supply risk

Supply risk is concerned with adverse "upstream" events in the service-oriented supply chain network that affect the ability of the focal firm to meet customer demands (both quantity and quality) within anticipated costs and time or cause threats to customer life and safety (Truong Quang & Hara, 2018). The firm is faced with supplier bankruptcy, price fluctuations, unstable quality and quantity of inputs, etc. (Quang & Hara, 2019; Shareef et al., 2020) which engender failures in delivering inbound goods or services to the purchasing firm and throughout the downstream service-oriented supply chain (Shareef et al., 2020).

For instance, tire quality in 2000 was found at Wilderness AT Firestone, killing and injuring numerous people in the US. Even worse, this unfavourable issue ended the nearly 100-year company relationship between Ford Motor Company and Firestone.

Similarly, in the case of Robert Bosch, the change in the quality of the high-pressure pump for the diesel fuel injection system in early 2005 resulted in significant production losses in most German automobile suppliers, affecting the entire supply chains. Moreover, lockdown because of pandemic gives rise to a shortage of disruptions, eventually resulting in supply-side shocks to the service-oriented supply chain (Barichello, 2020). Therefore, we propose the following hypotheses:

H2: Supply risk adversely affects Operational risk (H2a), Supplier performance (H2b), and Operational performance (H2c).

Operational risk

Operational risks are disruptions caused by appalling events within an organisation that influence a service-oriented supply chain's internal ability to produce goods and services, quality and timeliness of production, and/or profitability (Felfel et al., 2018; Truong & Hara, 2018). This reflects the challenge of determining optimal order and production quantities, safety stock levels, and other inventory policies that significantly affect service-oriented supply chain performance regarding costs and profitability (Felfel et al., 2018).

Mitsubishi Aircraft Corp. announced that the launch of the new Mitsubishi Regional Jet might be delayed for a fifth time due to technical problems, pushing down shares by 2.7% and extending their losses this year to 20%. Experts believed that any subsequent design changes could force Mitsubishi Aircraft to review production plans, leading to a substantial delay in the plane's delivery, but manufacturing operations had already started.

Strikes at two General Motors parts factories in 1998, resulted in the closure of 100 other parts factories, followed by 26 assembly plants, leaving dealer lots vacant for months.

Kate (2013) asserted that the majority of labour accidents resulting from employees taking more than three days off work – or affecting their ability to perform their usual duties – were caused by handling accidents. Although several accidents at work can have minor effects, their serious repercussions are insuperable. Hence, we propose the following hypotheses:

H3: Operational risk adversely affects Supplier performance (H3a) and Operational performance (H3b).

Demand risk

A service-oriented supply chain is driven by customer demand (Prasetyanti & Simatupang, 2015). According to Hançerlioullar et al. (2016), demand risk emerges from uncertainty around consumers' unpredictable needs (2016). Thus, the likelihood of customers placing orders with the focal firm, along with variations in volume and assortment, significantly impact the service-oriented supply chain network (Quang & Hara, 2019; Shareef et al., 2020). Taking these risks further prevents firms from anticipating market expectations (Yan et al., 2020), resulting in high costs, obsolescence, inefficient capacity utilization, disorganized operations, and poor customer service (Wagner & Bode, 2008; Yan et al., 2020).

Demand uncertainty causes order backlogs, planning problems, and the bullwhip effect, according to George et al. (2004). Changes in customer demand quickly raise product costs and harm stochastic inventory systems (Yan et al., 2020). Poor demand forecasts and inflexible procurement arrangements with downstream supply chain partners cost Cisco Systems Inc. $2.5 billion in inventory in 2001. Thus, we offer the following hypotheses:

H4: Demand risk adversely affects Operational risk (H4a), Operational performance (H4b) and Customer satisfaction (H4c).

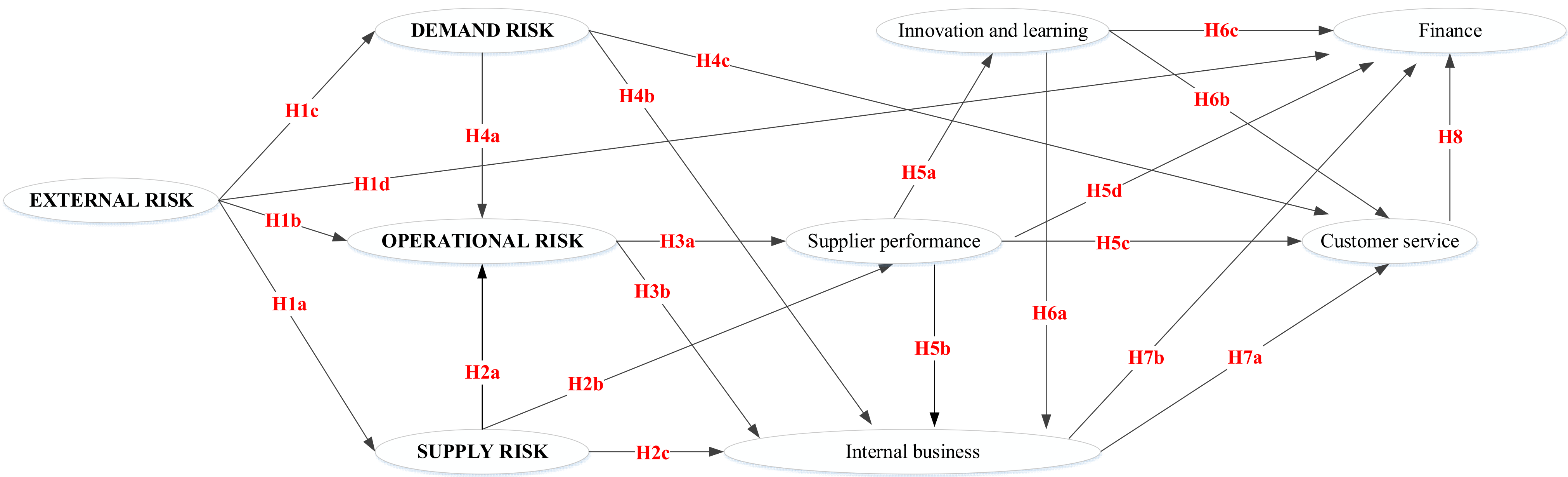


Figure 3 - Hypothesized model

On the right side of the model, Figure 3 graphically displays the postulated model of the relationship between risks and service-oriented supply chain performance. Principally, cost has been utilized to measure supply chain performance as a key performance indicator (KPI). The objective of supply chain management is to minimise costs and waste, allowing for a more efficient supply chain. Nonetheless, this metric is typically historical and does not indicate the current or future business performance (Quang et al., 2016).

Return on Investment (ROI) has been suggested as a "solution" to measure supply chain performance (Fernandes et al., 2017; Truong et al., 2017). The ROI, according to Quang et al. (2016), does not provide an objective assessment of the smaller businesses. This variable is beneficial for comparing similar companies in their industry, but it does not allow for cross-sector comparison.

Similarly, for evaluating firms in different industries, growth indicators such as revenue growth, profit growth, productivity growth, etc. become inconsequential. When compared to effective apparel businesses, an ineffective company underperforming in the software industry (a strong growth sector) will have greater revenue/profit growth, etc.

Apparently, financial measures are of paramount significance. However, in a comprehensive scale of service-oriented supply chain performance, more sophisticated, intangible, and strategic-oriented indicators must be balanced (Truong et al., 2017).

A modern methodology explains how short- and long-term indicators affect the success of service-oriented supply chains (Kaplan & Norton, 1992). As a result of this method, two conceptions arise:

- "Lagging" indicators, such as financial measures, describe what has transpired in the past.
- "Leading" measurements provide a forewarning of potential future events. Customer-oriented metrics, such as customer satisfaction, delivery timeliness, etc., or *innovation and learning-oriented metrics*, such as the number of new products developed anually, workforce flexibility, etc., are two examples.

Furthermore, Chopra and Sodhi (2012) and Quang et al. (2016) stated that supply chain management entails tracking and attempting to improve *operational and strategic performance measures*, as follows:

- *Operational performance:*
  - Supplier performance: reliability, response time.
  - Innovation and learning: number of a new product developed per year, workforce flexibility.
  - Operational performance: the amount of production waste, costs of inventory management, workforce productivity.
  - Customer satisfaction: delivery timeliness, percentage of "perfect orders" delivered, product value perceived by the customer, product/ service quality, response time to customer queries.

- *Strategic performance:* market share growth, return on investments (ROI).

The balanced scorecard approach, developed by Kaplan and Norton (1992), acknowledges the limits of traditional financial performance measurement and incorporates the strategy of a service-oriented supply chain into its performance goals. This approach also incorporates intangible assets including innovation, labour skills, supplier capabilities, and customer satisfaction (Truong & Hara, 2018). For long-term growth, this new approach shifts focus from physical assets to the physical and intangible resources of a service-oriented supply chain (Truong & Hara, 2018). This study identifies a set of service-oriented supply chain performance measurements, including (1) supplier performance, (2) innovation and learning, (3) operational performance, (4) customer satisfaction, and (5) finance, based on the balanced scorecard model.

Supplier Performance

High supplier performance must ensure that input materials meet quality requirements and needs (Quang et al., 2016). Suppliers are the driving force for new technology (Duong et al., 2019; Fernandes et al., 2017; Schiele, 2006) and innovation (Kaynak and Hartley, 2008). Understanding how suppliers can help a company innovate is critical (Schiele, 2006). Suppliers must be involved in the early stages of product conception and development. Suppliers' ability to provide creative, sustainable supply chain solutions adds value to sustainability and commercial performance (Schiele, 2006). The influence of buyer-supplier collaboration and supplier engagement in product development has been extensively studied (Kaynak & Hartley, 2008; Yeung, 2008). (Duong et al., 2019).

Furthermore, supplier performance is a crucial element in the long-term viability of the service-oriented supply chain. Service-oriented supply chains benefit from high-quality input provided on time and in the desired quantity, which enables them to prevent downtime, process deviation, and the level of damaged materials. High supplier performance can help reduce inventory, waste, and safety stock costs (Yeung, 2008). Hence, the following hypotheses are proposed:

H5: Supplier performance positively impacts Innovation and learning (H5a), Operational performance (H5b), Customer satisfaction (H5c), and Finance (H5d).

Innovation & Learning

Due to severe global competition, service-oriented supply chains must constantly enhance their products and processes. A service-oriented supply chain's value is proportional to the ability of innovation and learning which relates to the capacity to offer new goods, increase customer value, and improve operational efficiency (Quang et al., 2016). Service-oriented supply chain members can expand into new markets to maximize revenue and profit margins. According to Kaplan (2009), product and process innovation measures should be used to enhance delivery times, cycle times, defect rates, and productivity.

Inter-organizational learning enables enterprises discover new perspectives on strategy, markets, and relationships (Schiele, 2006). Their positive impact on supply chain performance indicators includes reduced cycle times (Boyer et al., 2003), increased resilience (Comfort, 1994), and increased relationship commitment (Boyer et al., 2003). This results in a broader pool of options to choose from and better implementation of those selected. The following hypotheses are offered:

H6: Innovation and learning positively impacts Operational performance (H6a), Customer satisfaction (H6b), and Finance (H6c).

Operational performance

The capability of service-oriented supply chain to minimise management costs/cycle times/lead times, improve quality/workforce/skills/productivity, and improve the efficiency of raw material utilisation and distribution capacity is operational performance compatible with business processes (Duong et al., 2019; Heizer et al., 2008; Truong & Hara, 2018). Kaynak and Hartley (2008) demonstrated that organisations with high operational performance generally produce excellent products/services, respond quickly to client requests, and deliver quickly to increase customer satisfaction and revenue..

By eliminating inessential costs, the prices offered to customers can be lowered (Truong & Hara, 2018). This increases customers' satisfaction (Duong et al., 2019), giving rise to a surge in market share and sales revenue (Truong et al., 2017). Additionally, increasing the efficiency of warehouse utilisation, machineries, and equipment, etc., improves return on assets (Kaynak & Hartley, 2008).

According to Kaplan (2009), outstanding customer performance is the result of procedures, activities, and decisions that occur throughout the firm. To meet customer expectations, a corporation should integrate customer orientation into operational performance measures. Hence, we propose the following hypotheses:

H7: Operational performance positively impacts Customer satisfaction (H7a) and Finance (H7b).

Customer satisfaction

Customers are an essential aspect of a service-oriented supply chain, and value-added activities focus on meeting their needs (Vargo & Lusch, 2008). Customers are primarily concerned about quality, delivery, price, and service. The service-oriented supply chain aims to "create value for consumers." Customers who are content with their products/services will not seek for alternatives (Fernandes et al., 2017). They are also less price-conscious and willing to pay a higher price, resulting in more sales revenue and profits. A satisfied customer will also recommend to other potential customers, thereby increasing market share. Hence, we propose the following hypotheses:

H8: Customer satisfaction positively impacts Finance.

3. Methodology

3.1 Instrument development

Only when an instrument can cover the content domain of each construct is it deemed effective (Li et al., 2005). Furthermore, the observed items measuring a construct should converge with each other and be distinguishable from those used to assess other constructs. Each construct should be reliable, succinct, and applicable. Hence, there are three following main stages to develop an effective instrument:

- Definitions of constructs and the corresponding observed items are on top of the agenda in the first stage.
- After an extensive literature review and revising based on a structural interview of academicians, the measuring scales are identified.

The Q-sort method is applied with the participation of nine top-level managers to initially review the reliability, validity, and one-dimensionality of research concepts. Table 1 describes the selected supply chain risk factors and service-oriented supply chain performance measurement.

Table 1 - Supply chain risk factors and Supply chain performance measures

	External risk	Supply risk	Operational risk	Demand risk
RISKS	Natural disaster	Selection of the wrong partner	Inventory holding cost	High competition in the market
	Political instability	Supplier bankruptcy	Design changes	Inaccurate demand forecasts
	External legal issues	Lack of integration with suppliers	Technological change	Demand uncertainty
	War and terrorism	Supplier opportunism	Warehouse and production disruption	Market changes
	Economic downturns	Suppliers' dependency	Labor disputes/ strikes	Customer dependency
	Government regulations	Supply responsiveness	Employee accidents	Customer fragmentation
	Fire accidents	Vague inspection/acceptance procedure of the supplier	Working conditions	High level of service required by customers
	Corruption	Price fluctuations	The products quality and safety	Deficient or missing customer relation management function
	Social and cultural grievances	Inability to handle volume demand changes	Insufficient maintenance	Low in-house production
	Decease Pandemic (Covid-19)	Inability to meet quality requirements	Variability in process	Order fulfilment errors
		Transport providers' fragmentation		Customer bankruptcy
		Transportation breakdowns		Receivables risk
		Port capacity and congestion		Reputation risk
	(Barichello, 2020; Dreher & Gassebner, 2013; Felfel et al., 2018; Hailu, 2020; Hançerlioğulları et al., 2016; Ivanov, 2021; Kate, 2013; Krause & Ellram, 2014; Meixell & Gargeya, 2005; Prasetyanti & Simatupang, 2015; Quang & Hara, 2019; Queiroz et al., 2020; Shareef et al., 2020; Truong & Hara, 2018; Truong Quang & Hara, 2018; Wagner & Bode, 2008; Yan et al., 2020)			

	Supplier performance	Innovation and learning	Operational performance	Customer satisfaction	Finance
SUPPLY CHAIN PERFORMANCE INDICATORS	Material cost	Number of a new product developed per year	Amount of production waste	Delivery timeliness	Market share growth
	Supply disruptions	Workforce flexibility	Costs of inventory management	Percentage of "perfect orders" delivered	Return on Investments (ROI)
	Reliability	Reducing new product launch times	Workforce productivity	Product value perceived by the customer	Return on Equity (ROE)
	Response time	Product development cost	Cycle time	Product/ Service quality	Return on Sales (ROS)
			Engineering efficiency	Product availability	Operating income

		Make improvements within a specific time period	Defect rates	Response time to customer queries	Sales
			Reducing setup times	Premium freight usage on both the inbound and outbound side	Cash-to-cash cycle time
		Specific improvement goals for the existing processes	Shipping and handling cost		Cash flow
			Efficiency use of facilities/ equipment		Revenue
			Production cost		Profitability
			Lead time		Shareholder value
			Order time		Sales growth
			Labor cost		
			Yield		
			Unit cost		
			Teamwork		
	(Boyer et al., 2003; Chopra & Sodhi, 2012; Comfort, 1994; Duong et al., 2019; Fernandes et al., 2017; Heizer et al., 2008; Kaplan, 2009; Kaplan & Norton, 1992; Kaynak & Hartley, 2008; Quang et al., 2016; Schiele, 2006; Truong & Hara, 2018; Truong et al., 2017; Vargo & Lusch, 2008; Yeung, 2008)				

A questionnaire containing these measuring variables is developed to obtain the opinions of those who are experienced in logistics and supply chain management. Respondents are asked to evaluate the impact degree of risks on their actual supply chain performance over the past five years. A five-point Likert-type scale is conducted with a value of 1 – expressing “strongly disagree”, and a value of 5 – expressing “strongly agree”.

3.2 Large-scale data collection

The empirical data analysed in this research are results of large-scale surveys supported by a Japanese government project and carried out in Vietnam's construction industry with approximately 6,600 companies. This project objective is a promotion of sustainable socio-economic development in the ASEAN region. Consequently, 285 usable responses are received, as shown in Table 2.

Table 2 - Sample characteristics

Company profiles	**Percentage**
Operation fields	
Building Material Manufacturing (sand, stone, additive, etc.)	14.74
Building Material Distribution	18.6
Concrete production	17.89
Construction executive	34.74
Design (architecture and construction)	12.98
Transportation	1.05

Respondent profiles	**Percentage**
Job title	
Top-level manager	5.26
Middle-level manager	21.75
First-level manager	46.32
Coordinator	16.49
Others	1.18
Working area	
Purchasing	4.21
Logistics	4.21
Operations/ Projects	55.44
Human Resources	9.12
Risk Management	3.86
Finance	2.46
Sales	14.74
Marketing	3.16
Others	2.81

3.3 Data analysis process

Non-response bias was applied to evaluate differences between respondents who replied to mail at the first time and those in the follow-up emails. The results of the independent T-test showed no significant conflict on average scores of all measured items, indicating non-response bias.

Empirical data are analysed based on Structural Equation Modelling (SEM). SEM considers two principal components for the procedure: (1) the cause-and-effect processes are formed by a sequence of structural equations, and (2) these causal relationships between concepts are demonstrated through a diagram to clarify the theory. Hair et al. (1995) asserted that to ensure the SEM technique is conducted effectively, the constructs and the corresponding observed items need to be analysed and refined for their reliability and validity. Traditional psychometric methods were applied with Cronbach alpha and Factor Analysis.

Tables 3 & 4 present the test results of measurement scales. Consequently, some variables were deleted from structural models due to not achieving a threshold value and all observed items load on the corresponding constructs with the minimum value of factor loading is .437, which entails that the measurement scales meet the standard criteria for convergent validity. Additionally, all item-to-total correlations are above .487, and the minimum value of Cronbach’s alpha coefficients is .742, which means the reliability of the constructs is achieved.

Table 3 - Test results of “risk”

Observed items	**Factor loadings**	

	Supply risk (1)	External risk (2)	Demand risk (3)	Operational risk (4)	Item – total correlation
External legal issues		.746			.536
Economic downturns		.758			.550
Fire accidents		.714			.487
Natural disaster		.713			.589
Decease Pandemic		.696			.564
Supplier bankruptcy	.802				.686
Price fluctuations	.775				.670
Inability to meet quality requirements	.519				.606
Transportation breakdowns	.697				.629
Design/Technological change				.750	.652
Warehouse and production disruption				.737	.620
Labour disputes/ strikes				.437	.586
Employee accidents				.522	.552
Inaccurate demand forecasts			.638		.538
Demand uncertainty			.564		.500
High level of service required by customers			.720		.612
Customer bankruptcy			.771		.628
Cronbach's Alpha	**.823**	**.769**	**.768**	**.792**	
Eigenvalue	**1.024**				
Variance Extracted	**68.328**				

Moreover, there are 4 factors of risk extracted at Eigenvalue =1.024 and Variance Extracted = 68.328 (Table 3) and 5 factors of supply chain performance were extracted Eigenvalue = 1.045 and Variance Extracted = 75.400 (Table 4). These results consolidated our conceptual model and proving the discriminant validity of constructs.

Table 4 - Test results of “supply chain performance”

Observed items	Factor loadings					Item – total correlation
	Customer satisfaction (1)	Operational performance (2)	Supplier Performance (3)	Innovation & Learning (4)	Finance (5)	
Reliability			.944			.700
Response time			.763			.700
Number of new product developed per year				.671		.620
Product development cost				.860		.620
Workforce productivity		.776				.699
Defect rates		.913				.699
Product availability	.541					.590
Delivery timeliness	.525					.580
Product value perceived by the customer	.918					.690
Response time to customer queries	.831					.740
Percentage of "perfect orders" delivered	.493					.520
Market share growth					.788	.530
Return on Investments (ROI)					.652	.530
Cronbach's Alpha	**.827**	**.804**	**.820**	**.768**	**.688**	
Eigenvalue	**1.045**					
Variance Extracted	**75.400**					

Moreover, there are 4 factors of risk extracted at Eigenvalue =1.024 and Variance Extracted = 68.328 (Table 3) and 5 factors of supply chain performance were extracted at Eigenvalue = 1.045 and Variance Extracted = 75.400 (Table 4). These results consolidated our conceptual model and proved the discriminant validity of constructs.

Results

Table 5 shows direct and indirect effects of risks on supply chain performance. Some notable results:

- The proposed risk model can be explained by 33.6% variance of Supplier performance, 46.4% Operational performance, 47.1% Customer satisfaction, and 46.5% of Finance.
- External risk including Covid-19 pandemic, causes supply unfulfillment, operational disruption, and demand fluctuation. There is no direct relationship found between External risk and Finance, but indirectly through other risks.

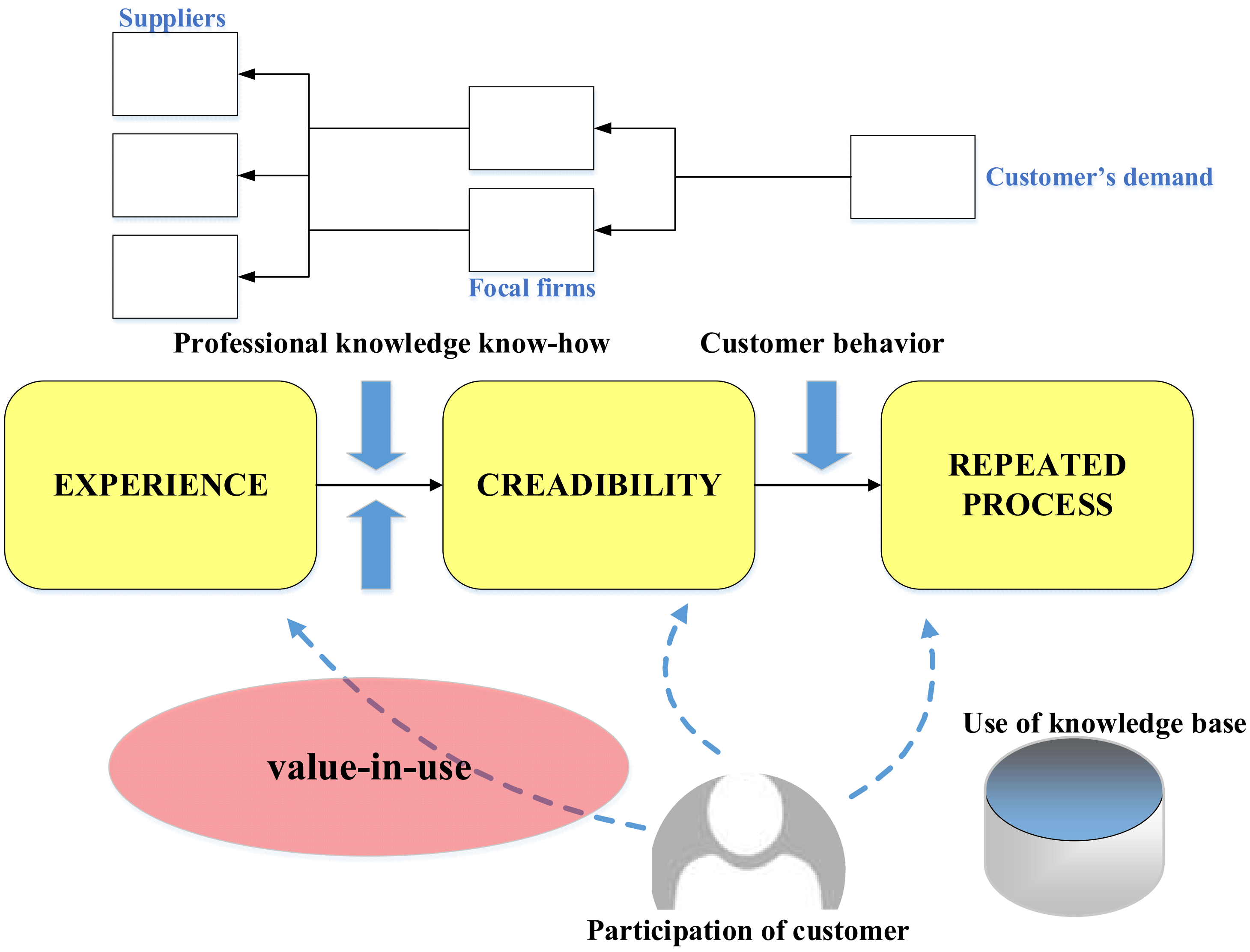
- Supply risk engenders fluctuations in raw materials. Consequently, firms have to stock, resulting in high inventory costs, which indirectly affects internal business efficiency. Moreover, we found indirect effects of supply risk on supplier performance through operational risk.
- Changes in design and technology of operational processes make suppliers fail to react in time, affecting supplier reliability and responsiveness.
- Risks have no impact on Innovation and learning.

Table 5 - Direct and indirect effects of risks on supply chain performance indicators.

Hypothesis	Statements			Results	Direct effect	Indirect effect
H1a	External risk	-->	Supply risk	.253	.253	0
H1b	External risk	-->	Operational risk	.124	.124	.185
H1c	External risk	-->	Demand risk	.121	.121	0
H1d	External risk	-->	Finance	Unsupported		.110
H2a	Supply risk	-->	Operational risk	.668	.668	0
H2b	Supply risk	-->	Supplier performance	Unsupported		.433
H2c	Supply risk	-->	Operational performance	.357	.357	.105
H3a	Operational risk	-->	Supplier performance	.647	.647	
H3b	Operational risk	-->	Operational performance	Unsupported		.028
H4a	Demand risk	-->	Operational risk	Unsupported		
H4b	Demand risk	-->	Operational performance	.245	.245	.020
H4c	Demand risk	-->	Customer satisfaction	Unsupported		.093
H5a	Supplier performance	-->	Innovation and learning	Unsupported		
H5b	Supplier performance	-->	Operational performance	Unsupported	.030	.013
H5c	Supplier performance	-->	Customer satisfaction	.225	.225	.027
H5d	Supplier performance	-->	Finance	.158	.158	.120
H6a	Innovation and learning	-->	Operational performance	.229	.229	
H6b	Innovation and learning	-->	Customer satisfaction	.248	.248	.063
H6c	Innovation and learning	-->	Finance	Unsupported	.008	.188
H7a	Operational performance	-->	Customer satisfaction	.277	.277	
H7b	Operational performance	-->	Finance	.225	.225	.121
H8	Customer satisfaction	-->	Finance	.437	.437	

Model fit: IFI = .918, TLI = .904, CFI = .916, RMSEA = .053, Chi-square/df = 1.797.
R^2 (Supplier performance) = .336, R^2 (Innovation and learning) = .023, R^2 (Internal business) = .464, R^2 (Customer service) = .471, R^2 (Finance) = .465

- Specially, only operational performance is affected by demand risk. Moreover, external risk has a tiny influence on demand risk. These findings emphasized the benefits of service-oriented supply chains, whose management begins with meeting customer needs (Sengupta et al., 2006; Vargo & Lusch, 2008). Thus, operations of the chain will minimize demand risk and its repercussions. Furthermore, production and consumption are concurrent in this type of business. Hence, values will be generated through consumption processes, known as value-in-use (Figure 4). Customers of service-oriented businesses expect high consistency and rarely switch services/companies once they accept one.



Source: Adapted from the research proposal of the project of "An Empirical Study on Services Value Chain based on the Experiential and Credibility Values"

Figure 4 - Service-oriented supply chain

5. Conclusions and future research

A powerful service-oriented platform is undoubtedly essential to turn supply chain management into a competitive advantage. Furthermore, a service-dominant logic approach should be included into supply chain management. As well as a series of interconnected value-creating actions performed by multiple stakeholders, the supply chain should be understood as a movement of products and a value constellation.

The risks within service-oriented supply chains have direct and indirect effects on the operation of such chains. From the study, service-oriented businesses provided a good observation for demand risk. Demand risk has the smallest impact on supply chain performance metrics, while external risk has a little impact on demand risk. These findings support the characteristics of a service-oriented supply chain, in which efforts and attention are directed towards meeting customer demand, resulting in demand-related risks being addressed and mitigated.

Furthermore, the proposed risk model constitutes 33.6% variance of Supplier performance, 46.4% Operational performance, 47.1% Customer satisfaction, and 46.5% of Finance. These are crucial ratios since supply chain performance is influenced by supply chain strategy, methods, etc. In other words, a company's supply chain performance will improve if these risks are effectively managed.

Our findings that supply chain risks, such as supply risks, operational risks, and demand risks, considerably influence supply chain performance, are comparable to those of Wagner and Bode (2008), Hendricks and Singhal (2003), and Hendricks and Singhal (2005). However, compared to our results, Wagner and Bode (2008) showed that supply risk and demand risk only explain .09 and .08 of the variances in supply chain performance, respectively. The two research approaches were distinct, yet the outcomes did not contradict each other. Unlike Wagner and Bode's (2008) approach, we examined both direct and indirect consequences. Practitioners are paying close attention to this Covid-19 pandemic-related empirical investigation. Thus, substantial supply chain risks immediately impacted respondents. Furthermore, the data used in this study came from Vietnamese enterprises. Therefore, the outcomes are only relevant to organisations with similar economic, political, cultural, and geographic conditions. Hence, future research should focus on repeating this study in diverse contexts with possibly varying risk profiles.

An innovative approach is to use strategic content/processes/contexts to explain service-oriented supply chain performance. The focus of previous qualitative and conceptual research has been on strategic content (Khan et al., 2008; Lin & Zhou, 2011). Some argued about operational risk and interruption risk (Svensson, 2007), while others offered generic guidance (Christopher & Peck, 2004). However, neither theories nor empirical research have comprehensively examined the implications of these tactics between risk and supply chain performance.

In the literature on supply chain risk management, resilience studies and disruption management receive less attention than studies on risk assessment and risk mitigation (Katsaliaki et al., 2021). Future supply chain risk management research should differentiate between risk-as an event and/or risk-as a process since they have different periodic effects on response management and resilience.

In an attempt to adequately address supply chain risks, (Carranza, 2008) proposed the following two approaches:

- Knowledge-based / knowledge-driven: refer to the judgement of the experts / decision-makers.
- Data-driven: aim at using empirical data.

The use of literature studies, Q-sort, and empirical data in the Vietnam construction industry to identify and assess supply chain risks is an innovative approach. As stated previously, future research can validate the conclusions in a different context/industry. A global poll will also reveal fascinating cultural differences in supply chain risk management.

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References

1. Barichello, R. (2020). The COVID-19 pandemic: Anticipating its effects on Canada's agricultural trade. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *68*(2), 219-224. https://doi.org/1.1111/cjag.12244

2. Boyer, K. K., Hult, G. T., & Frohlich, M. (2003). An exploratory analysis of extended grocery supply chain operations and home delivery. *Integrated Manufacturing Systems*, *14*(8), 652-663. https://doi.org/1.1108/09576060310503465

3. Carranza, E. J. M. (2008). *Geochemical anomaly and mineral prospectivity mapping in GIS*. Elsevier.

4. Child, J. (1972). Organizational structure, environment and performance: The role of strategic choice. *Sociology*, *6*(1), 1-22. https://doi.org/1.1177/003803857200600101

5. Chopra, S., & Sodhi, M. (2012). Managing risk to avoid supply-chain breakdown. *MIT Sloan Management Review (Fall 2004)*, *46*(1), 53-61.

7. Christopher, M., & Peck, H. (2004). Building the resilient supply chain. *The international journal of logistics management*, *15*(2), 1-14. http://dx.doi.org/1.1108/09574090410700275

8. Comfort, L. K. (1994). Risk and resilience: inter-organizational learning following the Northridge earthquake of 17 January 1994. *Journal of Contingencies and Crisis management*, *2*(3), 157-17. https://doi.org/1.1111/j.1468-5973.1994.tb00038.x

9. Dreher, A., & Gassebner, M. (2013). Greasing the wheels? The impact of regulations and corruption on firm entry. *Public Choice*, *155*(3), 413-432. https://doi.org/1.1007/s11127-011-9871-2

10. Duncan, R. B. (1972). Characteristics of organizational environments and perceived environmental uncertainty. *Administrative science quarterly*, *17*(3), 313-327. https://doi.org/1.2307/2392145

11. Duong, B. A. T., Truong, H. Q., Sameiro, M., Sampaio, P., Fernandes, A. C., Vilhena, E., Bui, L. T. C., & Yadohisa, H. (2019). Supply chain management and organizational performance: the resonant influence. *International Journal of Quality & Reliability Management*, *36*(7), 1053-1077. https://doi.org/1.1108/IJQRM-11-2017-0245

12. Felfel, H., Yahia, W. B., Ayadi, O., & Masmoudi, F. (2018). Stochastic multi-site supply chain planning in textile and apparel industry under demand and price uncertainties with risk aversion. *Annals of Operations Research*, *271*(2), 551-574. https://doi.org/1.1007/s10479-018-2980-2

13. Fernandes, A. C., Sampaio, P., Sameiro, M., & Truong, H. Q. (2017). Supply chain management and quality management integration: A conceptual model proposal. *International Journal of quality & reliability management*, *34*(1), 53-67. https://doi.org/1.1108/IJQRM-03-2015-0041

14. Flint, D. J., Lusch, R. F., & Vargo, S. L. (2014). The supply chain management of shopper marketing as viewed through a service ecosystem lens. *International Journal of Physical Distribution & Logistics Management*, *44*(1/2), 23-38. https://doi.org/1.1108/IJPDLM-12-2012-0350

15. Gamil, Y., & Alhagar, A. (2020). The Impact of Pandemic Crisis on the Survival of Construction Industry: A Case of COVID-19. *Mediterranean Journal of Social Sciences*, *11*(4), 122-122. https://doi.org/1.36941/mjss-2020-0047

16. George, A. Z., Lisa, M. E., Joseph, R. C., & Joseph, L. C. (2004). An analysis of supply risk assessment techniquesnull. *International journal of physical distribution & logistics management*, *34*(5), 397-413. https://doi.org/1.1108/09600030410545445.

17. Hailu, G. (2020). Economic thoughts on COVID-19 for Canadian food processors. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, *68*(2), 163-169. https://doi.org/1.1111/cjag.12241

18. Hair, J. F., Anderson, R. E., Tatham, R. L., & Black, W. C. (1995). *Multivariate data analysis with readings* (4th ed.). New Jersy.

19. Hançerlioğulları, G., Şen, A., & Aktunç, E. A. (2016). Demand uncertainty and inventory turnover performance: an empirical analysis of the US retail industry. *International Journal of Physical Distribution & Logistics Management*, *46*(6/7), 681-708. http://dx.doi.org/1.1108/IJPDLM-12-2014-0303

20. Hansen, E., Nybakk, E., & Panwar, R. (2013). Firm performance, business environment, and outlook for social and environmental responsibility during the economic downturn: findings and implications from the forest sector. *Canadian Journal of Forest Research*, *43*(12), 1137-1144. https://doi.org/1.1139/cjfr-2013-0215.

21. Heizer, J. H., Render, B., & Weiss, H. J. (2008). *Principles of Operations Management*. Pearson Prentice Hall. http://books.google.pt/books?id=044rAQAAMAAJ

22. Hendricks, K. B., & Singhal, V. R. (2003). The effect of supply chain glitches on shareholder wealth. *Journal of operations management*, *21*(5), 501-522. https://doi.org/1.1016/j.jom.2003.02.003

23. Hendricks, K. B., & Singhal, V. R. (2005). An empirical analysis of the effect of supply chain disruptions on long-run stock price performance and equity risk of the firm. *Production and Operations management*, *14*(1), 35-52. https://doi.org/1.1111/j.1937-5956.2005.tb00008.x

24. Ho, W., Zheng, T., Yildiz, H., & Talluri, S. (2015). Supply chain risk management: a literature review. *International Journal of Production Research*, *53*(16), 5031-5069. https://doi.org/1.1080/00207543.2015.1030467.

25. Ivanov, D. (2021). Exiting the COVID-19 pandemic: after-shock risks and avoidance of disruption tails in supply chains. *Annals of Operations Research*. https://doi.org/1.1007/s10479-021-04047-7

26. Jüttner, U. (2005). Supply chain risk management: Understanding the business requirements from a practitioner perspective. *The International Journal of Logistics Management*, *16*(1), 120-141. https://doi.org/1.1108/09574090510617385

27. Kaplan, R. S. (2009). Conceptual foundations of the balanced scorecard. *Handbooks of management accounting research*, *3*, 1253-1269. https://doi.org/1.1016/S1751-3243(07)03003-9

28. Kaplan, R. S., & Norton, D. (1992). The Balanced Scorecard: Measures that Drive Performance. *Harvard Business Review*, *70*(1), 71–79.

29. Kate, S. (2013). *Health and Safety Executive - Annual Statistics Report for Great Britain 2012/13*. Retrieved 07 June 2016 from http://www.hse.gov.uk/statistics/overall/hssh1213.pdf

30. Katsaliaki, K., Galetsi, P., & Kumar, S. (2021). Supply chain disruptions and resilience: a major review and future research agenda. *Annals of Operations Research*. https://doi.org/1.1007/s10479-020-03912-1

31. Kaynak, H., & Hartley, J. L. (2008). A replication and extension of quality management into the supply chain. *Journal of operations management*, *26*(4), 468-489. http://dx.doi.org/1.1016/j.jom.2007.06.002

32. Khan, O., Christopher, M., & Burnes, B. (2008). The impact of product design on supply chain risk: a case study. *International Journal of Physical Distribution & Logistics Management*, *38*(5), 412-432. https://doi.org/1.1108/09600030810882834

33. Krause, D., & Ellram, L. M. (2014). The effects of the economic downturn on interdependent buyer–supplier relationships. *Journal of Business Logistics*, *35*(3), 191-212. https://doi.org/https://doi.org/1.1111/jbl.12053

34. Li, S., Rao, S. S., Ragu-Nathan, T., & Ragu-Nathan, B. (2005). Development and validation of a measurement instrument for studying supply chain management practices. *Journal of operations management*, *23*(6), 618-641. https://doi.org/1.1016/j.jom.2005.01.002

35. Lin, Y., & Zhou, L. (2011). The impacts of product design changes on supply chain risk: a case study. *International Journal of Physical Distribution & Logistics Management*, *41*(2), 162-186. https://doi.org/1.1108/09600031111118549

36. Lusch, R. F. (2011). Reframing supply chain management: a service-dominant logic perspective. *Journal of supply chain management*, *47*(1), 14-18. https://doi.org/1.1111/j.1745-493X.201.03211.x

37. Meixell, M. J., & Gargeya, V. B. (2005). Global supply chain design: A literature review and critique. *Transportation Research Part E: Logistics and Transportation Review*, *41*(6), 531-55. http://dx.doi.org/1.1016/j.tre.2005.06.003

38. Prasetyanti, L. A., & Simatupang, T. M. (2015). A framework for service-based supply chain. *Procedia Manufacturing*, *4*, 146-154. https://doi.org/1.1016/j.promfg.2015.11.025

39. Quang, H. T., & Hara, Y. (2019). The push effect of risks on supply chain performance: service-oriented firms. *Business Process Management Journal*, *25*(7), 1734-1758. https://doi.org/1.1108/BPMJ-12-2017-0343

40. Quang, H. T., Sampaio, P., Carvalho, M. S., Fernandes, A. C., An, D. T. B., & Vilhenac, E. (2016). An extensive structural model of supply chain quality management and firm performance. *International Journal of Quality & Reliability Management*, *33*(4), 444-464. https://doi.org/doi:1.1108/IJQRM-11-2014-0188

41. Queiroz, M. M., Ivanov, D., Dolgui, A., & Wamba, S. F. (2020). Impacts of epidemic outbreaks on supply chains: mapping a research agenda amid the COVID-19 pandemic through a structured literature review. *Annals of operations research*. https://doi.org/1.1007/s10479-020-03685-7

42. Roberton, T., Carter, E. D., Chou, V. B., Stegmuller, A. R., Jackson, B. D., Tam, Y., Sawadogo-Lewis, T., & Walker, N. (2020). Early estimates of the indirect effects of the COVID-19 pandemic on maternal and child mortality in low-income and middle-income countries: a modelling study. *The Lancet Global Health*, *8*(7), 901-908. https://doi.org/1.1016/S2214-109X(20)30229-1

43. Schiele, H. (2006). How to distinguish innovative suppliers? Identifying innovative suppliers as new task for purchasing. *Industrial Marketing Management*, *35*(8), 925-935. https://doi.org/1.1016/j.indmarman.2006.05.003

44. Sengupta, K., Heiser, D. R., & Cook, L. S. (2006). Manufacturing and service supply chain performance: a comparative analysis. *Journal of supply chain management*, *42*(4), 4-15. https://doi.org/1.1111/j.1745-493X.2006.00018.x

45. Shareef, M. A., Dwivedi, Y. K., Kumar, V., Hughes, D. L., & Raman, R. (2020). Sustainable supply chain for disaster management: structural dynamics and disruptive risks. *Annals of Operations Research*. https://doi.org/1.1007/s10479-020-03708-3

46. Singh, S., Kumar, R., Panchal, R., & Tiwari, M. K. (2021). Impact of COVID-19 on logistics systems and disruptions in food supply chain. *International Journal of Production Research*, *59*(7), 1993-2008. https://doi.org/1.1080/00207543.202.1792000

47. Svensson, G. (2007). Aspects of sustainable supply chain management (SSCM): conceptual framework and empirical example. *Supply chain management: An international journal*, *12*(4), 262-266. https://doi.org/1.1108/13598540710759781

48. Thun, J.-H., & Hoenig, D. (2011). An empirical analysis of supply chain risk management in the German automotive industry. *International journal of production economics*, *131*(1), 242-249. https://doi.org/1.1016/j.ijpe.2009.1.010

49. Truong, H. Q., & Hara, Y. (2018). Supply chain risk management: manufacturing-and service-oriented firms. *Journal of Manufacturing Technology Management*, *29*(2), 218-239. https://doi.org/1.1108/JMTM-07-2017-0145

50. Truong, H. Q., Sameiro, M., Fernandes, A. C., Sampaio, P., & Duong, B. A. T. (2017). Supply chain management practices and firms' operational performance. *International Journal of Quality & Reliability Management*, *34*(2), 176-193. https://doi.org/1.1108/IJQRM-05-2015-0072

51. Truong Quang, H., & Hara, Y. (2018). Risks and performance in supply chain: the push effect. *International Journal of Production Research*, *56*(4), 1369-1388. https://doi.org/1.1080/00207543.2017.1363429

52. Vargo, S. L., & Lusch, R. F. (2004). Evolving to a new dominant logic for marketing. *Journal of marketing*, *68*(1), 1-17. https://doi.org/1.1509/jmkg.68.1.1.24036

53. Vargo, S. L., & Lusch, R. F. (2008). From goods to service (s): Divergences and convergences of logics. *Industrial marketing management*, *37*(3), 254-259. https://doi.org/1.1016/j.indmarman.2007.07.004

54. Vickery, S. K., Jayaram, J., Droge, C., & Calantone, R. (2003). The effects of an integrative supply chain strategy on customer service and financial performance: an analysis of direct versus indirect relationships. *Journal of operations management*, *21*(5), 523-539. https://doi.org/1.1016/j.jom.2003.02.002

55. Wagner, S. M., & Bode, C. (2008). An empirical examination of supply chain performance along several dimensions of risk. *Journal of business logistics*, *29*(1), 307-325. https://doi.org/1.1002/j.2158-1592.2008.tb00081.x

56. Wu, L.-C., & Wu, L.-H. (2015). Improving the global supply chain through service engineering: A services science, management, and engineering-based framework. *Asia Pacific Management Review*, *20*(1), 24-31. https://doi.org/1.1016/j.apmrv.2014.12.002

57. Yan, X., Du, S., & Hu, L. (2020). Supply chain performance for a risk inequity averse newsvendor. *Annals of Operations Research*, *290*(1), 897-921. https://doi.org/1.1007/s10479-018-3038-1

58. Yeung, A. C. L. (2008). Strategic supply management, quality initiatives, and organizational performance. *Journal of operations management*, *26*(4), 490-502. https://doi.org/1.1016/j.jom.2007.06.004.

Quality 4.0 on the small scale

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ABSTRACT

Purpose - According to the working definition of CQI on Quality 4.0, eight supporting principles underpin the definition. The examples aligned with those principles are global companies like Uber, Amazon, Airbnb, and the BMW Group. The paper analyzes the applicability of those principles in a much smaller case – how a Hungarian SME can benefit from Quality 4.0? What are the applicable elements in a small and medium-sized enterprise in Central Europe? The presentation is an interim report of our ongoing research at the Department of Management and Business Economics at the Budapest University of Technology and Economics.

Approach - A Hungarian enterprise was selected that applied for the Hungarian Government's funding project announced in 2017, which granted non-refundable financial aid to support the implementation of industry 4.0 in SMEs.

Findings - The conclusion is that the Széchenyi 2020 Project made a significant impact on PNH Ltd., the company chosen for the case study. The program allowed the organization to buy automated machinery, invest in industry 4.0, and expand its site. They successfully increased net sales and expanded the customer base. As an export-oriented company, they are able to not only satisfy the needs of national customers but meet the requirements of foreign customers and partners as well.

Research implications- Based on the benefits and requirements of the program with PNH Ltd.'s achievements, there is a high probability that the lack of disposable capital is the main reason SMEs similar to PNH cannot implement quality 4.0. However, with the help of EU funding, SMEs are able to acquire and successfully use Quality 4.0 tools.

Keywords: quality management, quality methods, implementation, digital quality.

Paper type: Case study

INTRODUCTION

Industry 4.0 brought many revelations, making digitalization and decentralization its main objective. Automated processes and machine learning allow series production with low scrap rates while being more time-efficient than ever before. To make these improvements possible, information technology needed to be reformed, resulting in the appearance of artificial intelligence (AI), the internet of things (IoT), and Big Data.

With enough funding and competence, the incorporation of industry 4.0's concepts should result in achieving the level of quality 4.0. To achieve a certain level of product quality, the whole organization needs to cooperate and make changes, as raw materials and machinery are not the only factors influencing the output.

In the European Union, SMEs (small and medium enterprises) represent 99 percent of businesses. As the integration of industry 4.0 was initiated by Germany, many organizations in the European Union followed their lead to stay in the competition. However, countries like Hungary have trouble keeping up with the modernization process, which is why we are researching the reasons and opportunities for SMEs in our country.

The development of industry has evolved through 4 stages, called the industrial revolution. The industrial developments of the 21st century are now the result of the fourth industrial revolution, called Industry 4.0.

Industry 4.0 has seen a huge evolution in production. As the life cycle of products has shortened, consumers are demanding more advanced products in greater quantities than ever before. (Gubán and Kovács, 2017) Meanwhile, the Covid-19 pandemic has had a major impact on the further development of the industry, as it has created a number of unprecedented challenges for companies. During the pandemic, it was not always possible to access the workplace, so it was necessary to continue working remotely. The main objectives of Industry 4.0 are digitalization and decentralization, which allow machines on the production line to be controlled remotely so that production can operate autonomously. (Gubán and Kovács, 2017) Connecting to global systems, Artificial Intelligence (AI), Machine Learning, the Internet of Things (IoT), and Big Data are essential elements for this development. These developments have created huge competition in the industry, requiring continuous adaptation and well-organized production, for which the development of appropriate quality management is essential.

Adapting to the challenges of the 21st century requires changes in quality management, which Quality 4.0 provides the solution. The definition of Quality 4.0 is complex and still a new concept. According to a definition by the Chartered Quality Institute (CQI), "Quality 4.0 is the harnessing of technology to engage people to improve the quality of an organization's products, services, and the outcomes they create." (CQI, 2021) Eight principles helped to develop this definition: shared value creation, mutual trust, cybernetics, rapid adaptive learning, transparency and collaboration, data value, cyber-physical systems, technology and combined intelligence. (CQI, 2021), In the 21st century, it is very important to have the right quality assurance, not only because of regulations but also because of the design of the right production process. It is not yet a generally accepted fact that Quality 4.0 is integrated into modern production.

In Hungary, in the interests of industry and quality development, the state has announced subsidies to help Hungarian SMEs to adapt to global industry trends in order to improve their competitiveness. Under these calls of a proposal, cohesion funds were available to applicant enterprises. The grants offered businesses the chance to acquire new equipment, develop automated production systems, and improve manufacturing technologies, industrial cyber applications, smart manufacturing, IoT solutions, and related information technology tools. By the end of the projects, Hungarian companies could join the global market with advanced technologies.

Quality 4.0 is important to make maximum and appropriate use of the technological achievements of Industry 4.0. In the 21st century phase of the industry, intelligent manufacturing robots will play an important role in production, requiring the right technological background. Their aim is to make flexible and customized production economical and to use resources efficiently. The equipment must be able to communicate with each other, which requires a centralized production management system for the flow of information. Virtual and real reality are merged during production, as the factory is able to self-regulate and optimize its operations. Virtual reality helps to detect possible errors in production, thus correcting errors in actual production. (Gubán and Kovács, 2017)

The technologies developed in Industry 4.0 provide the basis for self-regulating factories. There are three main areas of development in the world of business: the integration and digitalization of horizontal and horizontal value chains, the digitalization of products and services, and digital business models and customer relationships. The main technologies include cyber-physical production systems (CPPS), online networks that connect IT technology with mechanical or electronic components, able to communicate with each other over these networks. Machine-to-machine communication (M2M) allows devices connected to a network to communicate without human intervention. Artificial Intelligence (AI) enables machines to learn and reason, not only to follow a pre-written human program but also to perform more complex tasks autonomously. Horizontal and Vertical Systems Integration means that communication is being implemented in factories and throughout the entire distribution chain. Internet of Things (IoT) facilitates communication between machines, which is an information channel. Through this network, electronic machines are able to evaluate and control their environment, making production more efficient and economical. (Zonnenshain and Kenett, 2020), (Gubán and Kovács, 2017) Big data is the data set that smart grid systems require. The amount of data is huge and requires a lot of work to store, move, maintain and analyze. Cloud services are used to store software data. They are uploaded to a remote device in the "cloud", which, unlike local data storage, can retrieve information from anywhere with an internet-enabled device. Cybersecurity is closely related to Cloud Services, as data stored in the cloud requires access authorization. It is important to protect data properly to prevent possible cyber-attacks. Reality and virtual reality merge in production. Virtual reality is also necessary for design and production, as it helps to plan processes and contingencies. Without these elements, a company can lose out to the competition. (Gubán and Kovács, 2017)

In a modern factory, production has five main elements. For digital workpieces, the size, quality requirement, and sequence of the product are given. Intelligent machines communicate with the production control system and the digital workpieces, so the machine coordinates, controls, and optimizes itself. Through the vertical network connection, consumers provide the unique specifications for the product to be produced, which are transmitted by the production control system to the digital workpieces created by the automated rules. The products control their own manufacturing process by communicating with equipment, tools, and other workpieces about the conditions of production. Horizontal networking allows communication not only within a factory but also between manufacturers and suppliers throughout the supply chain. The aim is to increase production efficiency and use resources more economically. Smart workpieces monitor their own production process using sensors and controllers to ensure compliance with manufacturing standards. (Gubán and Kovács, 2017)

The use of quality management is essential to the use of the above elements, as Quality 4.0 is necessary to ensure quality and to implement the right process, which adapts to the developments of Industry 4.0. In the beginning, the industry mainly collected data on finished products, but with Big Data, various sensors, and modern data analysis methods, new possibilities for processing information have opened up. At that time, the concept of Quality 4.0 was not yet defined, so CQI started research on the subject.

The research was necessary because if the concept of Quality 4.0 is properly defined, it will help the quality management profession to govern and ensure that its obligations are properly met. The use of Quality 4.0 is still in its early ages, as the need for Industry 4.0 developments has only been accepted by the industry in recent years. Big corporations, like Nikon, realized the importance of Quality 4.0, where digitalized and automated production must run smoothly and without errors. (Nakayama, 2018)

To develop a working definition of Quality 4.0, CQI carried out the research in three phases. In phase 1, they reviewed literature in three overlapping disciplines: industry (I-4.0), quality (Q-4.0), and supply (chain SC-4.0). In phase 2, CQI did a survey and interviews on the subject and received insight from advisors and practitioners all across the globe. In Phase 3, they shared the research's outcomes with CQI members and other organizations. By the end of the research, CQI found eight components, which helped define Quality 4.0, they called the eight supporting principles. (CQI, 2021a)

The first principle is the Co-creation of value. This means that customers and society are constantly re-evaluating what they want to consume and how they require it. Consumers form co-creation through digital service. Co-creation involves all the occurrences where customers and companies generate value with interaction. (Dalli and Galvagno, 2014)

For example, Uber uses the Co-creation of value principle through their on-demand taxi service with effortless smartphone payment and a real-time feedback system. (CQI, 2021b) Firstly the rider gives their destination, then they offer different options on vehicle size, price, and drop-off time. After choosing the most suitable options, a nearby driver will see them and accepts their request. The rider is automatically notified when the driver's vehicle is about a minute away. Then the driver picks up the rider, and they confirm each other's information which is available for them. The app will give the driver directions, so the route is transparent for everyone involved. After the trip, the rider and driver rates each other on the app, as well as give the driver tip through the app. The company engages with customers to solve problems and help form new services. Customers are no longer interested in only owning a product or using it and demand products that can serve their needs in the long term. (CQI, 2021b)

The second principle is Mutual trust, which is crucial to rule out fear of surveillance and fraud. Through digital tools, transparency is easier to achieve. Data handling between systems is crucial for establishing mutual trust. Effective data systems should have the infrastructure for collecting, storing and using data. (CQI, 2021b) Mutual trust is essential between companies within a supply chain. When business partners have trust in a supply chain, they are more likely to share quality and relevant information with each other. If there is a lack of trust between contracted partners, inaccurate and low-value information would be distributed among the supply chain, which could lead to a possible loss of revenue. (Youn, S., Hwang W. and Yang, M. G., 2012)

The third principle is Cybernetics. Data is collected from various sources. Cybernetics is used to dynamically manage the whole system. A great example of this principle is the smart home, which uses systems such as Amazon Alexa, Hive, or Nest. Homeowners can easily control the heating and lighting systems from a distance. (CQI, 2021b) These technologies use machine learning to provide the highest customer satisfaction. This leads us to the next principal.

The fourth principle, according to the CQI, is Rapid adaptive learning. Continuous and rapid adaptive learning from data increases the value of a product. Customer expectations could be changed with prediction. A product's design and performance are communicated virtually, with agile development and system integration, there is a greater connectedness. For example, Airbnb has more than 100 machine learning models on its website. With the help of data, the system is able to make the customer's experience more customized. Rapid adaptive learning is using data to identify and recommend the most suitable options and get the customer to buy the product or service. (CQI, 2021b)

The fifth principle is Transparency and collaboration. The value chain is a network that connects cyber-physical systems. The systems are not in the traditional meaning, they create and exist in their own ecosystem, creating separate economies. The networks need strict regulations, and risk management is necessary to achieve well-functioning systems with great transparency and collaboration through expansion. (Bognár, Benedek, 2021) Fitness trackers are a great example of the mentioned principle.

Fitness trackers are capable of guiding the user and tracing their distance and speed. However, they could potentially have great risks without proper management. (CQI, 2021b) In the wrong hands and without strong cyber security, someone could potentially hack into the system and use the customers' data without permission.

The sixth principle is Data value, which is an important strategic tool that requires quality managers to have great knowledge about data and its governance, its architecture, and how to analyze it properly. Data must be identifiable and determinable; hence it could be used for future improvement for an organization. (PwC, 2019) (CQI, 2021b)

The seventh principle is Cyber-physical systems, which operate both by humans and machines as well. It is always changing, making formerly human tasks automated. The most obvious example of Cyber-physical systems is autopilot. (Eight Quality 4.0 principles, CQI, 2021) It is an aircraft flight management system that allows flying as the safest means of transport. Autopilot drives the vehicle automatically with the parameters set by the pilot. It has been used since 1914. In this age, we have self-driving cars, which have evolved through the years. The Tesla models are becoming more common all over the world, they are capable of driving automatically, but they need human intervention. (CQI, 2021b)

The last and eighth principle is Technology and combined intelligence. Technology and combined intelligence are the basic technology that uses machine learning and artificial intelligence, which expand human intelligence. With the combination of human and machine, the real and virtual world co-exist, which allows the machine element to react, learn, make decisions by itself and optimize the production process. For the eighth principle, BMW group's is a great example of using technology and combined intelligence in practice. In their manufacturing line, BMW uses artificial intelligence to estimate part photos from the production line. It filters out elements that do not meet quality standards. (CQI, 2021b)

METHODS

Our research group has just started research on the effectiveness of Quality 4.0 implementations from state-funded programs. There will be interviews and fiscal analysis with cooperative organizations. This first review is based on the publicly available information of one organization from the sample set.

RESULTS

The Széchenyi Plan 2020 is an ongoing financial funding project in Hungary to help these businesses' technological improvement, specifically to aid them in implementing the elements of Industry 4.0. (Palyazat.gov)

Our case study is based on one of the Széchenyi 2020 development plans announced in 2017: the GINOP-1.2.8-20-2020-01115 plan. Its aim was to financially aid SMEs with implementing industry 4.0 and quality 4.0 elements, like the automation of production processes, networking of industrial systems, and their digital transformation.

The networking of production processes, the networking of industrial processes, and the interoperability of industrial applications are made possible by digitalizing the operation of enterprises engaged in productive activities. It was and is necessary to prepare domestic small and medium-sized enterprises for the transformation, as this is the main group of companies that are capable of developing the Hungarian industry. (GINOP, 2020)

Unfortunately, in Hungary, the industrial digital readiness and the efficiency of production are still significantly lagging behind its European competitors. Therefore, the call supported SMEs that were selected under the project to help the automation of production processes with various CPPS (Cyber-Physical Production System) solutions applied to cyber-industrial production systems. The industrial SMEs that were qualified were able to benefit from the development of their technological systems, production and production systems, management, and control systems, etc.

The projects that met the conditions of the call for proposals were awarded between 20-500 million HUF. (GINOP, 2020)

The call's requirements included elements that supported the implementation of Industry 4.0 and Quality 4.0. These requirements were: the development of automated production systems, development of manufacturing technologies, process automation tools, sensor, and control technologies, using robotics; industrial cyber applications, smart manufacturing, machine-to-machine, IIoT (Industrial Internet of Things). Moreover, the acquisition of manufacturing license, manufacturing know-how, and intangible assets related to the acquisition of new equipment. (GINOP, 2020)

This paper researches how governmental funding can help SMEs integrate towards quality 4.0, to see how they can benefit from the development.

From the list of SMEs that were qualified, we chose to start our analysis with PNH (Production Network Hungary), as their activity is related to our studies, and the company has implemented industry 4.0 elements since its founding.

The main activity of the company is the production of pellet-fired fireplaces and boilers of various capacities. Due to the production's complexity, the company has only a few competitors. They are specialized in series production, mainly dealing with complete projects and their overall management, including procurement and logistics. They are also capable of accepting special orders: making parts for working and power machines and fuel tanks.

After receiving funding from the government and building their portfolio and circle of customers, they started manufacturing railway telecommunications containers. (PNH, 2022)

In addition to a large number of manual tools, PNH Ltd has a significant amount of high-value and state-of-the-art equipment at its production site: energy-saving but highly efficient laser cutting equipment with automated service units, bending robot cells, pc-controlled edge bending equipment, welding robots, plate rolling machines, welding machines, pulse welding machines, waterjet cutting equipment, stud welders, electric and diesel-powered forklifts in the logistics area, surface treatment on the grit blasting line, automated powder coating and varnish painting lines. (PNH, 2022)

Its objective is to be present in various markets, develop and maintain a reliable network of partners, stability, and competitive advantage. PNH is an export-oriented company with an average export rate of 90%+. The business mainly sells to Austria, France, and Germany. (PNH, 2022)

Their plan with the funding received from the GINOP project was to install PLC (programmable logic controller) controlled, automated Trubend 7000 bending machines. They needed this improvement in technology because the scrap rate was too high with their current (2017) technology, so the new drive machine should reduce this. Also, the production time and lead time of the products would be reduced due to the new machines. The automatized technology is capable of picking up the material prepared on the pallet, processing it, and then depositing it in the prepared storage. The capacity of the laser cutter is matched by the performance of the machines, and the two technologies together enable the company to increase production capacity while improving product quality and cost-efficiency. The project also included an investment in the production of products for renewable energy. (PNH, 2022)

The company already used technology fit for Industry 4.0. They used and are still using MES (Manufacturing Execution System) for real-time data collection. They are continuously analyzing data and reject rate detection. The Ulysses enterprise management system is in use, which aids in gathering and storing data required by Industry4.0's standards. The system allows both automatized data gathering and manual data gathering possible. They are not only gathering data from the production line and also monitoring the satisfaction of customers, employees, and business partners. (PNH, 2022)

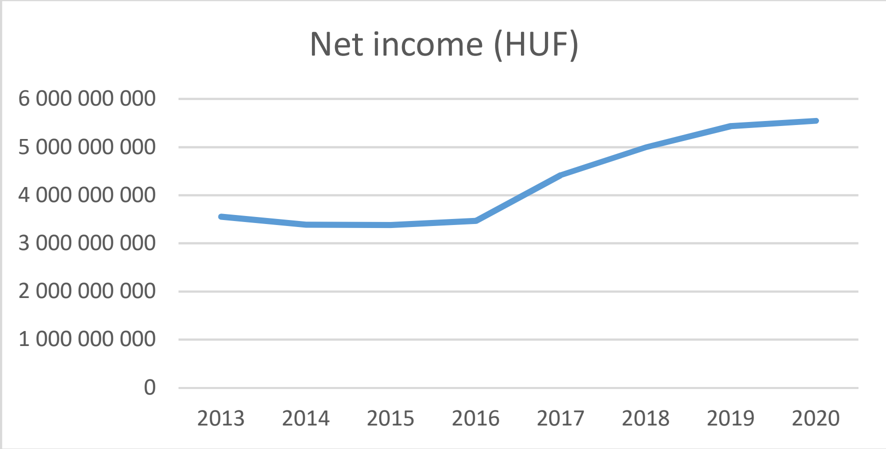
Alongside with their technology, their business and welfare perspective also fits the requirements of quality 4.0. Their mottos include: "stay up to date", "always be up-to-date - in fact, technologically always be one step ahead", "always be efficient - by constantly striving to innovate and staying human", "be supportive- be part of the whole, part of the team". (PNH, 2022).

The enterprise focuses on the continuous improvement of technology and tries to adapt to the current and future needs of their customers. They are investing in automated production machines, which is the reason they applied for the funding project. The modernization of machinery requires adaptive learning; therefore, the company requires employees to attend training to be able to provide great quality products while keeping the human error rate low (PNH, 2022)

With the GINOP program, the company was able to expand its factory from 10500 m^2 to 15000 m^2, and they are continuing to grow. In 2017 they established office structures. In 2018, they built a new factory hall and bought bending robots, and in 2019 they bought powder coating machinery. (PNH, 2022)

The companies that were qualified for the financial funding project had to choose one obligatory term from the following three: the companies either increase their net sales, increase their operating profit, or the business employ at least five permanent employees at the project site from the start of the project at the latest until the end of the maintenance period of the project. (GINOP, 2020)

PNH chose to increase its net sales. With the new technology, lower fault rate of products, and their enlarged workforce, they were able to realize bigger profits.



During the first year of the funding (2017), they realized 950 535 000 HUF more than the previous year. In 2018 they increased their net income to 4 996 768 000 HUF, in 2019 to 5 439 225 000 HUF, and in 2020 to 5 546 249 000 HUF. This means they were able to grow their net income 112.8% annually. These are based on the public financial statements of the company. (Ministry of Justice, 2022)

The company is ISO 9001 compliant, and it is certified by TÜV SÜD. (PNH, 2022).

Apart from growing their annual income, there is further research needed to conclude other benefits of the GINOP program and the usage of quality 4.0 elements.

Unfortunately, the paper at this time can only be written using publicly available information and most companies are withholding much information to strengthen their competing position. We are in negotiation with the financing agency to support our research.

In the future, interviews and a more thorough financial analysis will be made. The future goal of our research is to determine how much the integration of quality 4.0 changes enterprises and product quality. Also, the interviews will hopefully provide enough information to conclude which were the crucial points during the enterprises' development and what expected and unexpected risks quality 4.0 raises. Furthermore, it can potentially offer opportunities that could only be obtained by development.

CONCLUSIONS

Based on our study, we concluded that the funding of SMEs (small and medium enterprises) provided by the government, which is funded by the European Union, is needed in the Hungarian economy. Many businesses like PNH benefited from the financial support and are able to improve their technologies to a level required by industry 4.0. Qualifying for these requirements is a base ground for reaching quality 4.0.

Most enterprises struggle with implementing the elements of quality 4.0, because it doesn't stop with the automatization of production, a low scrap rate, and time efficiency. The leader of the organization needs to create specific and challenging goals and always seek improvement; the management should be able to provide a working environment where the employees are trained and up to date with their knowledge. Clear and fast internal communication is necessary, especially while analyzing data. The internal IT (informational technology) system and software must support the databases needed for executing the aspired quality level.

The rapid growth and change in technology is a challenge both financially and on an organizational level for most businesses, but the Széchenyi 2020 funding program aids the integration towards a more modern and adaptive operation.

REFERENCES

Bognár Ferenc, Benedek Petra (2021), The role of partial risks in the risk assessment process: A case study for compliance risks, In: „New Trends and Challenges in Management. Special Focus on Process Management and Industry 4.0", University of Debrecen

Broday, E. E., (2021), The evolution of quality: from inspection to quality 4.0, International Journal of Quality and Service Sciences, doi: 10.1108/IJQSS-09-2021-0121

CQI (2021a), Defining Quality 4.0 https://www.quality.org/quality-4-point-0 [10.03.2022]

CQI (2021b), Quality 4.0 principles https://www.quality.org/quality-4-point-0 [18.03.2022]

Dalli, D., Galvagno M. (2014), Theory of value co-creation: a systematic literature review focus on quality 4.0, Journal of Service Theory and Practice 24(6), pp. 643-683

Ghobakhloo, M., (2019), Industry 4.0, digitization, and opportunities for sustainability, Journal of cleaner production, Volume 252 No. 119869, p 3.

GINOP (2020): Founded project GINOP-1.2.8-17: https://www.palyazat.gov.hu/doc/4380 [10.04.2022]

Gubán, M., Kovács, Gy. (2017), INDUSTRY 4.0 CONCEPTION, available at: https://www.researchgate.net/profile/GubanMiklos/publication/317012611_INDUSTRY_40_CONCEPTION/links/591eb52f45851540595eacc0/INDUSTRY-40-CONCEPTION.pdf [30.03.2022]

Hwang W., Yang, M. G., Youn, S., (2012), The Role of Mutual Trust in Supply Chain Management: Deriving From Attribution Theory and Transaction Cost Theory, International Journal of Business Excellence, 5(5), p. 588

Kenett, R. S., Zonnenshain A., (2020), Quality 4.0—the challenging future of quality engineering, Quality Engineering 32(4) p. 617

Kumar, R. R., Ganesh, L.S., and Rajendran, C., (2021), Quality 4.0 – a review of and framework for quality management in the digital era, International Journal of Quality & Reliability Management, 39(6), pp. 1385-1411. doi: 10.1108/IJQRM-05-2021-0150

Dan Jacob, (2017), Quality 4.0 Impact and Strategy Handbook - Getting Digitally Connected to Transform Quality Management, LNS Research.

Ministry of Justice, (2022), E-Statements https://e-beszamolo.im.gov.hu/oldal/kezdolap [10.04.2022]

Nakayama, T. 2018. Nikon opens up about its strategic focus on Quality 4.0 https://blog.nikonmetrology.com/nikon-strategic-focus-quality-4-0 [29.03.2022]

PNH Ltd., (2022), Company website: https://pnh.hu/hu/rolunk/ [28.04.2022]

PwC, (2019), Putting value on Data https://www.pwc.co.uk/data-analytics/documents/putting-value-on-data.pdf [10.04.2022]

Rodič, B., (2017), Industry 4.0 and the New Simulation Modelling Paradigm, Organizacija, 50(3), pp. 193-207. doi: 10.1515/orga-2017-0017

Saihi, A., Awad, M., and Ben-Daya, M., (2021), Quality 4.0: leveraging Industry 4.0 technologies to improve quality management practices – a systematic review, International Journal of Quality & Reliability Management, doi: 10.1108/IJQRM-09-2021-0305

Sony, M., Antony, J. and Douglas, J. A., (2020), Essential Ingredients for the Implementation of Quality 4.0: A narrative review of literature and future directions for research, The TQM Journal, 32(4), pp. 779-793. doi: 10.1108/TQM-12-2019-0275

Analysis of ISO 9001:2015 certification in Portugal and comparison with other countries: effects of development scores, crisis, and economic cycles

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STRUCTURED ABSTRACT

Purpose - Quality management systems implemented in accordance with ISO 9001:2015 are internationally recognized since the standard is universal. Currently, certification in this area is in high demand, so it is interesting to understand how different countries use these quality management systems to promote their success.
Design/methodology/approach - From this perspective, a data survey was carried out regarding the number of companies certified by ISO 9001:2015 in Portugal and several countries, split into three groups according to their Gross Domestic Product (GDP) and Human Development Index (HDI). The first group consists of countries scoring some the highest values in terms of GDP and HDI (respectively China and Norway); the second one consists of countries with low scores in their GDP and HDI (Niger and Tuvalu); and the third group lists countries with fair scores in both indexes (Slovakia and Israel). This study shows the evolution of ISO 9001 certification in Portugal over the years and compares it with other countries with varying development scores. In depth studies were made on the industrial sectors that make greater use of certification in Portugal, and to the possible impacts of economic cycles and crisis.
Findings - No sharp or long-lasting decreases were identified following major economic events, either national or global. In the particular case of Portugal, it was observed that despite a decrease in certification after the 2012 crisis, such decrease it was neither long-lasting nor very significant in relation to previous years.

Keywords: ISO 9001:2015; Quality Management Systems, Sustainable Development

1. Introduction

The need to produce better products, reduce costs and exceed customer expectations regarding quality and business competitiveness have been some of the concerns that companies face now a days in order to achieve a good market positioning (Junior, Queiroz, and Queiroz, 2014). Customers and consumers alike find numerous options of establishments and organizations with the best products and services at their disposal. Thus, it is up to every single organization to differentiate and innovate, always adapting to what the customer is looking for: product quality (Bento, 2022). In this sequence, it is possible to understand that organizations operate in a complex environment, with intense technological changes and constant swings in consumer's demand standards. This leads them to have to constantly adapt so as not to lose market space (Maekawa, Carvalho, and Oliveira, 2013). Regarding, organisations should implement methodologies and instruments that enable the achievement of continuous improvement, leading to the standardisation of procedures, cost reduction and competitive advantages in relation to the surrounding market. The adoption of continuous improvement through Quality Management Systems (QMS) has become the most widely adopted tool by organizations for quality management, motivation of the workforce, process control, identification of requirements and meeting customer needs (Maekawa, Carvalho, and Oliveira, 2013; Costa, 2013). Thus the search for excellence related to quality management practices leads to an increasing number of companies seeking certification in ISO 9001. In this context, the present document has as main objective to evaluate the evolution of the quantity of companies that have been certified at the level of Quality Management Systems, through the ISO 9001 standard, from 1993 to 2019.
Furthermore, it's also a goal to carry out a comparative analysis between Portugal and the more and less developed countries, in order to understand if there are significant differences between them. In a more specific analysis, to evaluate the evolution of the ISO 9001 standard in Portugal and to verify in which of the sectors there is a greater adherence to the Quality Management System. Thus, in a first phase, the theoretical review is carried out on the Quality Management System and the respective ISO 9001 Standard. Next, the methodology of how the following work was developed is presented. The subsequent chapter presents the results and respective analysis of all the data showb and finally the conclusion of the work and the respective bibliochartical references is drawn up.

2. Theoretical framework

The ISO 9001 standard consists of a management system based on processes, which provides the certified companies with the ability to achieve goals, as well as to raise the level of efficiency at production level and the delivery of products/services. In other words, it is a guideline that, when applied allows the optimization of processes and to streamline the production strategy, boosting customer satisfaction (Duarte, 2014; Furniel, 2020).

In the business sector, quality certification is increasingly required for the right reasons, although there are still those who want to obtain it only for marketing purposes. In this sense it is important to highlight that, when an appropriate stimulus occurs, the implementation of ISO 9001:2015 enables numerous advantages, among which we can highlight (Junior, Queiroz, and Queiroz, 2014; APOPARTNER, 2018; Portaliso, 2020):

- Company credibility: obtaining certification in ISO 9001:2015 transmits stability to the market, since it consists of an internationally recognized standard, which stands out for the continuous improvement of processes;
- Customer satisfaction: the implementation of the ISO 9001:2015 standard has at its core the focus on the customer, that is, it gives importance to the requirements and needs imposed by the same. As a result, a significant increase in the profitability of the organisation will be verifiable;
- Assertive decisions: evidence-based decision making is one of the principles of the standard that provides an improvement in efficiency and minimisation of costs. This is feasible due to the continuous adaptation of the strategy to the client.

However, considering certification in a short period of time, even for the right motivations, may lead to some problems. High costs are one of the negative aspects, since implementing the standard in a short period of time requires the acquisition of consultants so that the indispensable requirements can be fulfilled quickly. Implementing the whole process too quickly can also wear on the responsible team, as they must implement the essential requirements at short notice. Consequently, there will be an inadequate adaptation of the processes, since the analysis of the organization and its data is residual (Maekawa, Carvalho, and Oliveira, 2013; Perdigão, 2016; VG - Comunicação, 2017).

In this sense, to achieve success in the implementation of ISO 9001:2015 it is necessary to perform a sequence of actions. In the first phase it is essential to acquire knowledge about the advantages, as well as the implementation methodology, in order to identify the potential adjustments to be made. Next, the team should be established, taking into consideration the employees who show interest and motivation in implementing the standard, a key characteristic to achieve success. Subsequently, an evaluation of the current quality management system should be carried out in order to identify non-compliant requirements. This means that changes will have to occur so that the requirements demanded by ISO 9001:2015 are correctly fulfilled. It should be noted that these changes will be outlined by consultants, who will minimise as far as possible the disruption to the operation (Costa 2013). Finally, it is fundamental to carry out an internal audit, i.e., a previous procedure similar to an external audit that grants the possibility to verify if the requirements inherent to the certification are being correctly fulfilled. This information is the basis for proceeding or not to the external audit. In case the internal audit verifies the compliance of all the requirements imposed by the standard, it is necessary to contact the certifying entity, so that the final assessment may be carried out, i.e., the external audit which will result in the certification (Cota and Freitas, 2013; VG - Comunicação, 2017).

In short, obtaining ISO 9001:2015 certification means that the organisation has an internationally recognised quality management system, as it meets the required requirements (VG - Comunicação, 2017).

3. **Research Methodology**

As previously mentioned, the main goal of this article is to evaluate the evolution of the number of companies that have been certified at the level of Quality Management Systems, through the ISO 9001 standard, from 1993 to 2019. Furthermore, it aims to carry out a comparative analysis between Portugal and the more and less developed countries (in accordance with their GDP and HDI scores), in order to understand if there are significant differences between them and identify if there are global trends in the way these number evolved (say, for example, in the face of international disruptive events or economic crisis). As a departure point, and in a more specific analysis, this article evaluates the evolution of the ISO 9001 standard in Portugal and to identifies in which sectors there is a greater adherence to the standard.

Research was carried out on the subject so that it was contextualised with the evolution of the ISO 9001:2015 standard in Portugal, as well as in other countries.
Next, and since the intention was to compare Portugal with the most and least developed countries, through consultation of the respective Human Development Index (HDI) (Ruic Gabriela, 2020) and the Gross Domestic Product (GDP) (Index Mundi, 2020) it was decided which countries would be studied - Niger, Slovakia, Israel, Norway, China and Tuvalu. Subsequently, the international website *ISO - Committee Past Surveys* (ISO - International Organization for Standardization, 2020) was used and data on the number of certified organizations per year from 1993 to 2019 for each selected country was collected. In order to make the interpretation of the collected data easier, we have prepared a group of tables, in which we calculated the percentage of increase or decrease between each year, with the intention of understanding in a more efficient way how was the evolution of the ISO 9001 standardization throughout time. Subsequently, chartical representations were developed to allow for a comparative analysis between Portugal with the selected countries and therefore base our discussion and conclusions upon them.
For the more specific analysis referring to Portugal, the website of the Portuguese Institute for Accreditation (IPAC) was used, where the data relating to the number of companies certified by the ISO 9001:2015 standard between 2017 and 2020 was collected (IPAC - Instituto Português de Acreditação, 2020). It is noteworthy that the data observed on the ISO website between 2017 and 2020, do not coincide with the data observed on the IPAC website, relating to Portugal, being the error on the part of one of the platforms. In addition to this data, we studied which sectors have the highest number of certified companies in Portugal.

4. Empirical Findings

4.1. Evolutionary analysis by country

Certification is certainly a strategic option for organizations development in the way that it shows a will to improve and be competitive in the market. As the main objective of this study is to understand the evolution of the ISO 9001:2015 standard over the years and to verify if it varies from country to country, data was collected regarding 7 different countries - Portugal, Niger, Slovakia, Israel, Norway, China and Tuvalu. The choice of these countries was not random, and the criteria used was their GDP and HDI scores. It was found that Niger and Tuvalu are evaluated as undeveloped countries due to their GDP and HDI, Slovakia and Israel are evaluated as medium/fair scores (and equivalent to Portugal) because their GDP and HDI scores, and Norway and China are classified as the most developed countries in the world because they have the highest GDP and HDI. Furthermore, in order to understand if disruptive incidents and economic crisis affected the number of companies certified, our study identified major historical events (Table 1) that could have ha dan impact in the behavior of these organizations).

Table 1. Relevant situations in world economy – Crisis years

1994	Emerging markets crisis
1997	2nd wave of the crisis of the emerging markets
2008	Subprime crisis – World Crisis
2012	European debt impact
2020	COVID-19 (economic growth)

After gathering all the data, it was possible to evaluate the adoption of the standard between 1993 and 2019, in each selected country. These events are represented in the charts for each country's analysis.

Portugal

In Portugal, an analysis of the chart in Figure 1 shows that there has been a positive evolution of the standard. There was an exponential increase between 1993 and 2006, with a decrease (-10%), although not very significant, between 2007 and 2009, perhaps explained by the world crisis that occurred in 2008. After a slight increase in 2010, there was a significant drop (-20%) in 2011, the lowest percentage since 2004. Despite the European debt that occurred in 2012, there follows an increase, relative to 2011, of 30%, with the highest point of certification in 2014, with 8006 certified Portuguese companies. Since then, the number of organisations adhering to the standard has been decreasing, on average 5.55% per year. However, it will subsequently be seen that in 2020 there was an increase of 5% compared to 2019.

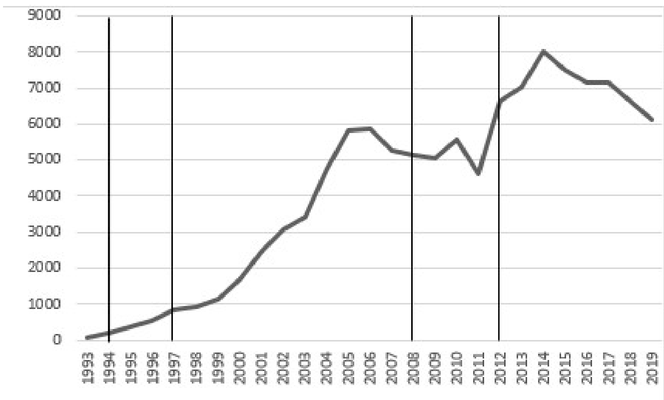

Figure 1. ISO 9001:2015 certification - evolution in Portugal (1993-2019)

Tuvalu

As a very small country and one of those scoring the least in terms of GDP, the evolution of Tuvalu was evaluated as a very single case, being considered an extremely singular example. The country has less than 12,000 inhabitants a high poverty rates, with lack of resources for sustainable growth and poverty reduction (Raglow 2020). It should be noted that in Tuvalu the number of companies in the country is very small, which may lead to such low values and variations. Figure 2 shows that the maximum number of certified companies is one and that that number is neither stable nor sees gradual evolution.

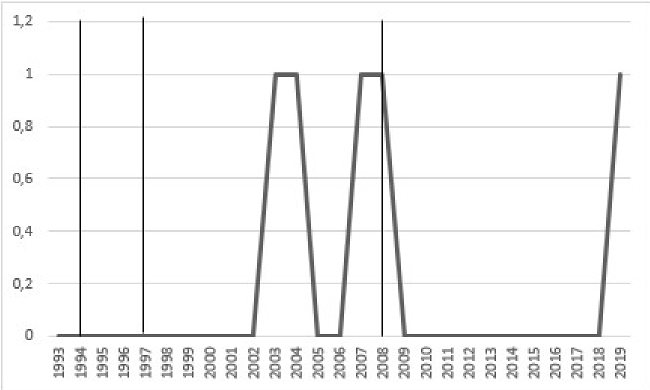

Figure 2. ISO 9001:2015 certification - evolution in Tuvalu (1993-2019)

Niger

Niger is considered the least developed country in terms of the Human Development Index. Figure 3 shows that certification of organisations only started in 2006, with only one company. In 2008, there was a considerable increase, with about 34 companies certified. However, in the following years there was a sharp drop (-750%), followed by another significant increase in 2017, returning to 36 certified companies. The number subsequently drastically dropped again in 2018, showing a very unstable trend subject to single circumstances.

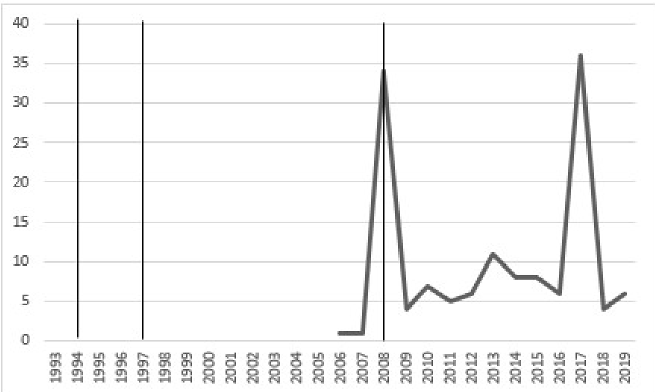

Figure 3. ISO 9001:2015 certification - evolution in Niger (1993-2019)

Slovakia

In Figure 4, the evolution of the ISO 9001:2015 standard in Slovakia is represented. Slovakia is a developed country, with a medium-high scores. In this figure it is possible to observe that the evolution of the standard has been mostly marked by steady increase but has decreased in recent years. Through the chart we can see an increase, with slight decreases, between 1993 and 2017, and in the latter, there was a sharp decrease in 60% of the certifications. In 2018 there was again a (slight) increase, resulting in a total of 4012 certified companies.

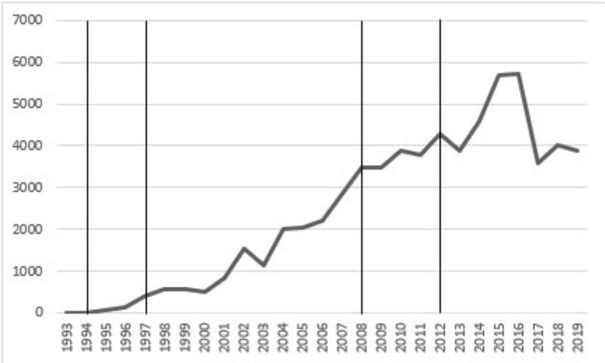

Figure 4. ISO 9001:2015 certification - evolution in Slovakia (1993-2019)

Israel

The chart in Figure 5 shows a positive increase in the number of certifications over the years, with the greatest decrease, around 70%, occurring in 2008, most probably due to the world crisis at the time. After 2008, there has been a gradual increase in the number of companies signing up for certification, with slight decreases. Like Slovakia, Israel is considered a developed country, especially at the level of GDP.

Figure 5. ISO 9001:2015 certification - evolution in Israel (1993-2019)

Norway

Figure 6 shows the evolution of the ISO 9001:2015 standard in Norway. This is one of the most developed countries in the world in terms of HDI, and was therefore selected to analyse its evolution and in this way understand the differences with Portugal. The chart shows that, like the other countries analysed previously, it has a positive evolution over the time period under analysis, with the sharpest drops occurring in 2002 (-27%) and 2012 (-11%), given that in 2012 the countries suffered economically due to the European debt. In 2016 there is also a sharp decrease, of about 27%. Since that there has been a favourable evolution.

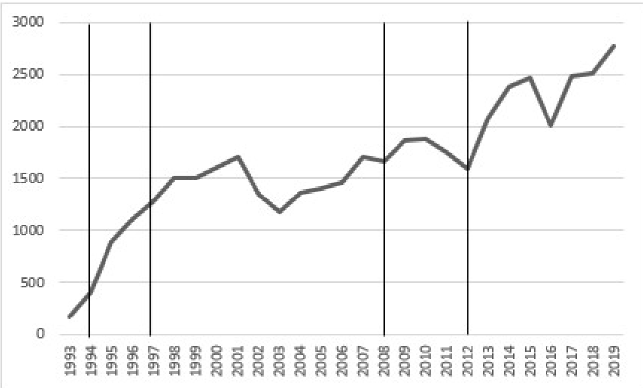

Figure 6. ISO 9001:2015 certification - evolution in Norway (1993-2019)

China

China is considered the most developed country in terms of GDP and is also one of the countries with the greatest number of companies in the world. It is important to note that in the countries previously studied, the vertical axis, relative to the number of certified companies, varies between 0 and 12.000, and in this case, it varies between 0 and 450.000, which allows us to understand the size of the country in question. Figure 7 shows that between 1993 and 2000, although there is an increase, it is not very significant. After 2000 until 2017 there is an exponential increase in the number of companies adhering to certification, with the highest percentage, about 17%, that is, 350.631 certified organisations, occurring between 2016 and 2017. In 2018 there is a decrease of 33%, with a small increase in 2019, with a total of 280.386 certified companies.

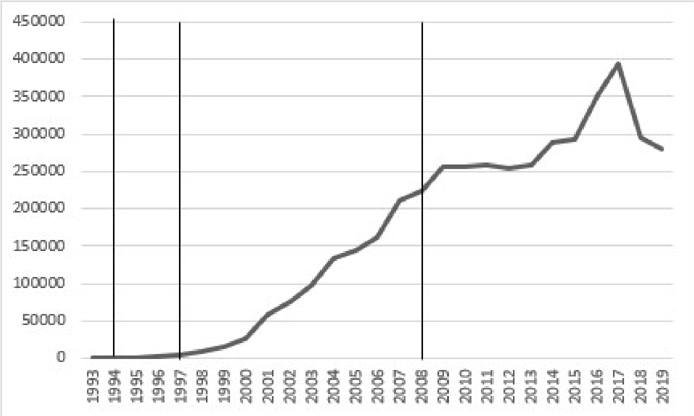

Figure 7. ISO 9001:2015 certification - evolution in China (1993-2019)

From all the charts presented it is possible to conclude that there are no clear global trend of decrease in years of crisis, and therefore it does not seem to be key factor for companies adhering or not to certification.

4.2. Comparative Analysis between Portugal and other countries

After the individual analysis of each country, a comparison was made between them, in order to determine whether their behaviour, despite the differences in development, was equivalent or very different.

Portugal vs. Slovakia

Slovakia is, according to the HDI, a country on par with Portugal. In this perspective, using ISO data, a comparative chart between both countries was carried out. The variations between each year were calculated as percentages in order to understand if the behaviour between both countries was similar, which may be seen in Figure 8.

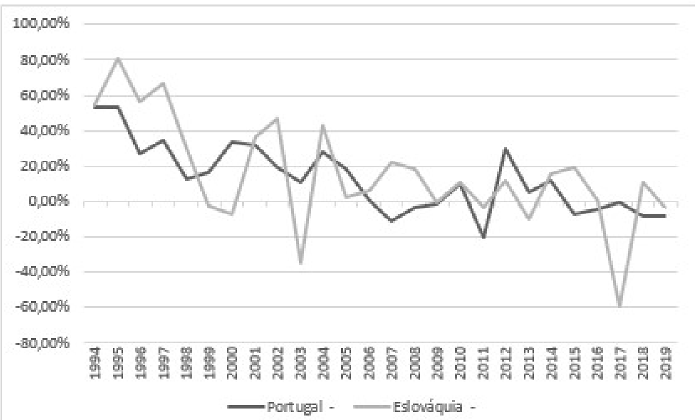

Figure 8. Chart comparing Portugal and Slovakia

The analysis shows that the variability in the number of certifications is more extreme in Slovakia, although the positive and negative oscillations are identical to Portugal. In 1999/2000, Slovakia shows a drop in the number of certifications much higher than Portugal, as well as in 2003. However, between 2006 and 2009, while there was an increase in certifications in Slovakia, in Portugal there was a slight decrease, which may be justified by the global crisis. In 2012, despite being the year in which there was the greatest impact of the European debt, the countries under study showed a considerable increase. However, in 2017, there was a drastic decline in Slovakia, which was followed by a slight instability, since there was an increase and decrease in 2018/2019, respectively.

Portugal VS Israel

Israel is considered a country on par with Portugal in what refers to the GDP scores. Comparing both countries delivered the results showed in the chart in Figure 9.

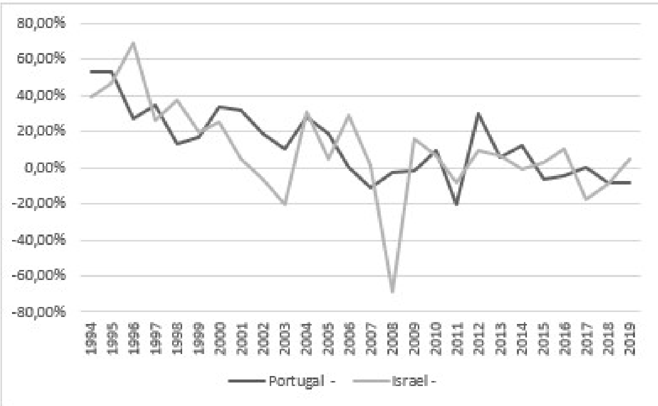

Figure 9. Chart comparing Portugal and Israel

We may conclude that Israel is extremely like Portugal regarding the variability of the ISO 9001:2015 standard certification numbers. Despite this evidence, the presence of a clearly identifiable outlier in 2008 should be highlighted, which may be justified by the strong impact of the global crisis in the country. Apart from this, in 2003 there is also a significant difference given that in Portugal there is an increase in certifications, even if considered slight, and in Israel there is a very significant decrease.

Portugal vs. Norway

Norway is the most developed country in the world according to the HDI.

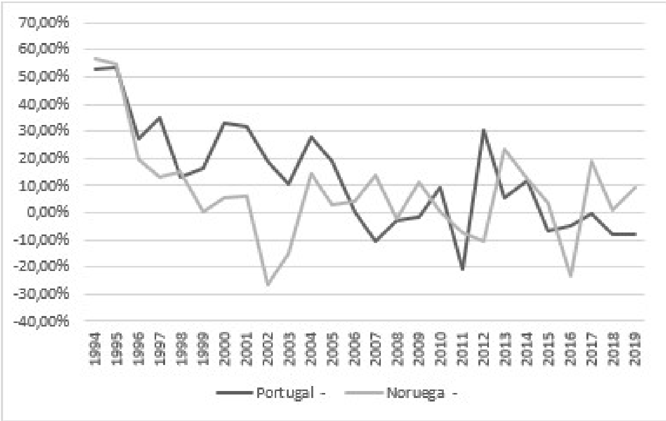

Figure 10. Chart comparing Portugal and Norway

Analysing the data resulting from the comparison between Norway and Portugal, it can be seen that the two countries have shown an increase in the number of certified companies from 1994 to 2002. In this year at Norway, the number of certified companies decreased by 26.71% compared to the previous year. On the other hand, Portugal continued to show growth until 2006. In 2007, Portugal presented one of its greatest decreases, while Norway had an increase of 13.86% in certified companies. Contrary to Portugal, which has been showing a decrease since 2015, Norway has shown a slight increase, excluding only 2016 when it showed a decrease of 23.23%. Thus, it is possible to conclude that despite these differences, and by analysing the chart in Figure 10, Portugal has a similar behaviour to Norway.

Portugal vs. China

Currently, according to its GDP, China is considered the most developed country in the world. The comparison between it and Portugal resulted in the chart shown in Figure 11.

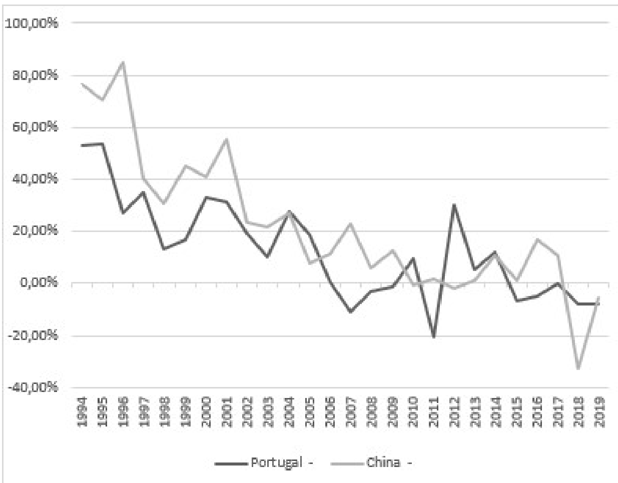

Figura 11. Chart comparing Portugal and China

By analysing the data, it can be seen that although the two countries have a considerable difference in the number of overall certified companies, a similar trend is observed in both countries. Both show enormous growth rates of certified companies between 1994 and 1995. In 2007, there is a decrease in the number of certified companies in Portugal, and this decrease continues until 2009. China, on the other hand, shows growth which, despite not being very high from year to year, leads to more companies being certified by ISO 9001. In 2010, China shows a decrease of 0.79% of certified companies whereas, in the same year, Portugal recovers and shows an increase of about 9.61%. In 2012 the global crisis had a negative impact in China, specifically leading to a decrease of about 1.84% of certified companies, however, there was an increase of more than 30% of certified companies in Portugal. Since 2015, the number of certifications in Portugal has been decreasing, while in China this phenomenon began in 2018.

In the cases of Niger and Tuvalu, no comparisons were made, since it is already clear from the charts presented in the previous section that due to the reduced number of certifications, any comparison and representation of the content, at a percentage level, is not reliable, which is why it will not be presented.

4.3. Portuguese National Panorama

In order to understand the evolution of ISO9001 certification in Portugal, an annual quantitative study was carried out on the number of companies that adhered to the certification in question. It is important to mention that the data under study were obtained through the collection of statistical data made by the Portuguese Institute for Accreditation (IPAC), and that incoherencies were identified with the data made available by ISO. Thus, Table 2 was obtained from the data collected.

Table 2. Certified companies between 2017 and 2020

ISO 9001:2015	2017	2018	2019	2020
Certified companies	5837	5743	5827	6147
Correlation	-	-2%	1%	5%
	-	Diminished	Increase	Increase

From this a chart was made, represented in Figure 12, which allows a faster and more objective way to verify the national evolution.

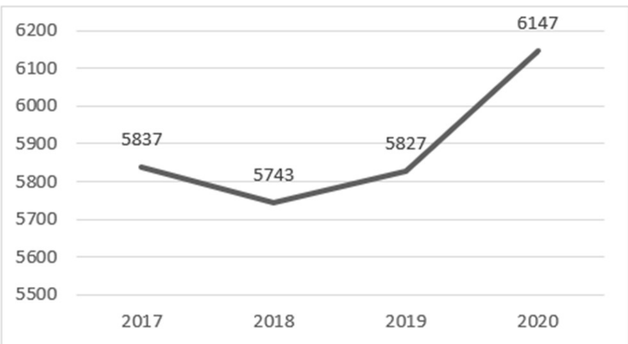

Figure 12. ISO 9001:2015 certification – recent evolution in Portugal (2017-2020)

Analysing Table 2 and the chart represented in Figure 12, it is possible to see a decrease of 2% from 2017 to 2018. Since then, a positive progress prevails, although a more notable increase is observed between 2019 and 2020. It should be noted that, although there is an increase in adherence to certification in Portugal, certification numbers are still far away from their highest point in 2014 (see Figure 1).

After understanding the evolution of the standard at a national level, we proceeded to a more specific investigation, with the objective of understanding which of the national sectors would correspond to the highest percentage of certification. From this study, it was found that the variability between sectors in terms of ISO 9001:2015 certification is considerable, and the same is proven by Table 3, which contains the data, collected from the IPAC website, relating to the number of certified companies by sector in the year 2020. It is important to note that after studying the data, it was found that the sum of the number of companies by sector in the year 2020 was 7715, which is higher than the total number of certified companies in the respective year referred by IPAC.

Table 3. Number of certified companies by activity sector (IPAC - Instituto Português de Acreditação 2020)

Setor	**Quantidade de Empresas certificadas**
Agriculture, forestry, livestock, hunting and fishing	114
Mining and quarrying	363
Food, beverages and tobacco	588
Textile industry	175
Leather and leather products industry	35
Manufacture of wood and of products of wood and cork	92
Manufacture of pulp, paper, cardboard and derivatives	79
Editing	4
Printing, services related to printing and reproduction of recorded media	96
Manufacture of coke and refined petroleum products	2
Nuclear fuel processing	0
Manufacture of chemicals and chemical products (except pharmaceutical products)	140
Pharmaceutical manufacturing	14
Manufacture of rubber and plastics products	203
Manufacture of other non-metallic mineral products (except cement, lime, plaster and concrete products, gypsum, etc.)	105
Manufacture of cement, lime, plaster and concrete products, plaster, etc.	71
Basic metals and metal products industry	646
Manufacture of machinery and equipment	310
Manufacture of electrical and optical equipment	197
Shipbuilding and ship repair	7
Aircraft and spacecraft manufacturing	2
Manufacture of transport equipment (except shipbuilding and repair, manufacture of aircraft and spacecraft)	51
Furniture manufacturing; other manufacturing	138

Recycling	48
Production, transmission and distribution of electricity	17
Production and distribution of gas through pipelines	20
Water production and distribution	43
Construction	585
Wholesale and retail trade; repair of motor vehicles, motorbikes and personal and household goods	1054
Accommodation and catering (restaurants and similar)	53
Transport, storage and communication	393
Financial and real estate activities; renting of machinery and equipment without operator and of personal and household goods	113
Information and computer technologies	212
Research and development; architecture, engineering and related techniques	407
Other services	428
Public administration, defence and compulsory social security	125
Education	154
Health and Social Security	417
Other community, social and personal services	187
Non classified or identified	27

From the table presented, a chart was prepared, represented in Figure 13, with the intention of visualising the exposed data more easily.

ISO 9001:2015;

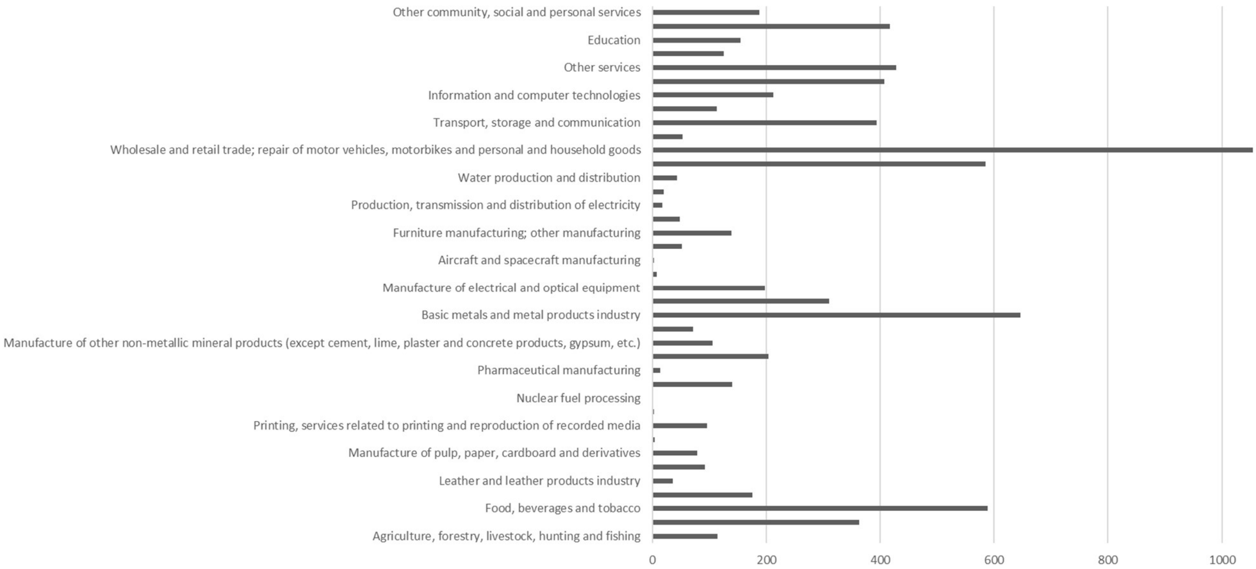

Figure 13. Chartical analisys per activity sector

According to the 2020 data, only one of the forty sectors analyzed did not carry out any certification. Looking at the chart in Figure 13 and at Table 3, it can be seen that the sector that most adhered, based on IPAC's classification, was the “Wholesale and Retail Trade”, with a total number of 1054 companies. This is followed, with around half of the certifications of the previous sector, by the “Metallurgical Industry”, with 646 companies, “Construction” (585 companies) and “Food Industry, Beverages and Tobacco” (588 companies). On the other hand, there is a set of activities whose adherence to certification is extremely residual. Among the sectors with the lowest adherence, the following can be highlighted negatively “Nuclear fuel treatment” (0 companies),” “Refined petroleum products” (2 organizations), “manufacture of aircraft and space vehicles” (2 organizations), “Publishing”, with 4 companies and “Shipbuilding and Ship Repair” (7 companies).

It is important to mention that the activity sectors with a higher number of certified companies correspond to industries with a higher activity in Portugal, and the sectors with less certified companies correspond to sectors with little presence in Portugal. That is, the sectors with higher qualification are proportional to the sectors with higher presence in Portugal, and hence the justification for the number of certified companies.

5. Discussion and Conclusions

Several relevant conclusions can be drawn from this article. Firstly, and as it was possible to verify throughout the report, the quality management system implemented in accordance with ISO 9001:2015, is recognised both nationally and internationally, being applied from the less developed countries to the most developed ones, considering their evaluation at the level of GDP and HDI.
Regarding the evolutionary analysis by country, it was found that in all the countries studied, there is a gradual increase pattern in the number of companies certifying themselves according to the quality standard, with small oscillations. However, recent years have seen some relevant decreases or stagnation.
Other aspects to be evaluated were the fact that there were no sharp or long-lasting decreases in following major economic, either global or national. In the case of Portugal, it was observed that despite a decrease after the 2012 crisis, such decline it was neither long-lasting nor very significant in relation to previous years.

The comparative analysis between countries with different development scores showed similar trends, despite any differences in the socioeconomic conditions of each country. The number of certified companies in the period analysed was equivalent, with the percentages of increase and decrease being very close and coincident. An important point to be analysed is the fact that China is a country with unique economic conditions and much higher scores both in terms of GDP and HDI, than Portugal. However, the variation and trends in are very close, which allows us to conclude that despite the existing economic differences between the countries, this is not a key factor for companies to adhere to certification.

Looking specifically at Portugal, level there has been a positive increase in the number of certified companies, with the highest growth (5%) being observed from 2019 to 2020. The fact that companies feel the need to produce better products, reduce costs and exceed the expectations of customers regarding quality and business competitiveness has been one of the key points for them to join quality management systems to satisfy the customer and achieve a good market position. In addition to this evolution, it was verified which sectors contribute the most to certification in Portugal: wholesale and retail trade, with a total number of 1054 companies, the metallurgical industry, with 646 companies and the construction industry (585 companies). These values can be explained by the fact that they are the sectors with the highest number of enterprises in Portugal. On the contrary, the sectors with the fewest certified companies are the treatment of nuclear fuel (0 companies) and the production of refined petroleum products (2 organisations).

References

Bento, Maria. 2022. "A IMPORTÂNCIA DA GESTÃO DA QUALIDADE COM A IMPLEMENTAÇÃO DA ISO 9001 PARA O DESENVOLVIMENTO E MELHORIA DA EMPRESA SOFTCOM TECNOLOGIA."

Costa, Sónia. 2013. "Passos Para a Implementação de Um Sistema de Gestão Da Qualidade Numa Instituição de Ensino Superior."

Cota, Kely, and Maria Freitas. 2013. "Gestão Da Qualidade, Um Desafio Permanente: Um Estudo de Caso Sobre o Processo de Manutenção de Um Sistema de Qualidade Em Uma Indústria Metalúrgica," 64–83.

Duarte, João. 2014. "ISO 9001:2015, UMA OPORTUNIDADE PARA O REAJUSTAMENTO DAS EMPRESAS NO SECTOR METALÚRGICO METALOMECÂNICO."

Index Mundi. 2020. "Produto Interno Bruto (PIB) - Comparação Entre Países." 2020. https://www.indexmundi.com/g/r.aspx?v=65&l=pt.

IPAC - Instituto Português de Acreditação. 2020. "IPAC." 2020. http://www.ipac.pt/pesquisa/pesq_empcertif.asp.

ISO - - International Organization for Standardization. 2020. "ISO - International Organization for Standardization." 2020. https://www.iso.org/sites/outage/.

Junior, Mauro, Fernanda Queiroz, and Jamerson Queiroz. 2014. "ISO 9001-UMA REVISÃO DA LITERATURA SOBRE SEUS BENEFÍCIOS, MOTIVAÇÕES E DIFICULDADES." *Congresso Nacional de Excelência Em Gestão*, August.

Maekawa, Rafael, Marly Carvalho, and Oliveira Otávio. 2013. "Um Estudo Sobre a Certificação ISO 9001 No Brasil: Mapeamento de Motivações, Benefícios e Dificuldades Study on ISO 9001 Certification in Brazil: Mapping the Motivations, Benefits, and Difficulties."

Raglow, Annie. 2020. "Poverty in Tuvalu: An Example for Other Countries." 2020. https://borgenproject.org/poverty-in-tuvalu/.

Ruic Gabriela. 2020. "Os Países Mais e Menos Desenvolvidos Do Mundo Em 2019 | Exame." May 20, 2020. https://exame.com/mundo/os-paises-mais-e-menos-desenvolvidos-do-mundo-em-2019/.

VG - Comunicação. 2017. “O Que é o Selo ISO 9001 e Para Que Serve? - Consultoria On-Line.” 2017. https://www.consultoriaiso.org/o-que-e-o-selo-iso-9001-e-para-que-serve/.