Lean six sigma 4.0 methodology for optimizing occupational exams in operations management

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Abstract

Purpose – This paper explores Lean Six Sigma principles and the DMAIC (define, measure, analyze, improve, control) methodology to propose a new Lean Six Sigma 4.0 (LSS 4.0) framework for employee occupational exams and address the real-world issue of high-variability exams that may arise.

Design/methodology/approach – This study uses mixed methods, combining qualitative and quantitative data collection. A detailed case study assesses the impact of LSS interventions on the exam management process and tests the applicability of the proposed LSS 4.0 framework for employee occupational exams.

Findings – The results reveal that changing the health service supplier in the explored organization caused a substantial raise in occupational exams, leading to increased costs. By using syntactic interoperability, lean, six sigma and DMAIC approaches, improvements were identified, addressing process deviations and information requirements. Implementing corrective actions improved the exam process, reducing the number of exams and associated expenses.

Research limitations/implications – It is important to acknowledge certain limitations, such as the specific context of the case study and the exclusion of certain exam categories.

Practical implications – The practical implications of this research are substantial, providing organizations with valuable managerial insights into improving efficiency, reducing costs and ensuring regulatory compliance while managing occupational exams.

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Originality/value – This study fills a research gap by applying LSS 4.0 to occupational exam management, offering a practical framework for organizations. It contributes to the existing knowledge base by addressing a relatively novel context and providing a detailed roadmap for process optimization.

Keywords Lean six sigma, Industry 4.0, Interoperability, DMAIC methodology, Occupational exams

Paper type Research paper

1. Introduction

With the advent of globalization, companies are facing a need to adapt their systems to thrive in dynamic markets and meet evolving customer expectations (Chacko, Suresh, and Sreenivasan, 2023). To sustain development and growth, many companies are adopting Industry 4.0 (I4.0) technologies and process improvement methodologies (Ariente *et al.*, 2016; Marshall *et al.*, 2012; Psarommatis *et al.*, 2022). Among these lean management methodologies and I4.0 technologies are widely used (Antony *et al.*, 2023). By combining the lean six sigma (LSS) tools and I4.0 technologies, organizations can effectively apply these practices in operations management, leading to significant improvements in lead-time, cost, rework and waste reduction (Dombrowski and Mielke, 2014; Franchetti, 2015; Kumar *et al.*, 2016; León and Calvo-Amodio, 2017; Sordan *et al.*, 2022).

According to Werkema (2013), six sigma projects for product and process improvement follow a standardized approach known as DMAIC (define, measure, analyze, improve, control) that serves as a fundamental infrastructure element within the six sigma methodology. By integrating various quality tools throughout each stage of the DMAIC process, organizations can establish a systematic method focused on continuously improving product and service quality while minimizing defects (Maleyeff *et al.*, 2012; Pongboonchai-Empl *et al.*, 2023). In support of this, Servin *et al.* (2012) emphasized the pivotal role of process improvement in creating a competitive advantage for organizations, enabling the generation of value within the operational system. This signifies that investments in process improvements should be carefully planned and controlled to ensure maximum efficiency and meet the requirements of both internal and external customers (Leite and Montesco, 2016).

The primary emphasis of this study revolves around the process of defining occupational exams in accordance with the Brazilian Regulatory Standards, called Norms Regulated (NR): NR 7 – Occupational Health Medical Control Program (PCMSO) [1] and NR 9 – Program for the Prevention of Environmental Risks (PPRA) [2], as outlined in Ordinance No. 3.214 (Ministério do Trabalho, 1978). In his work, Ribeiro (2014) already highlighted the lack of instruments for the evaluation of PCMSO, which is considered a management system. However, occupational physicians also need additional tools to ensure that the program effectively achieves its objectives of disease prevention, tracking, early diagnosis and management of diagnosed cases to prevent further complications.

Thus, this research aims to explore the application of LSS principles, along with the DMAIC methodology, in the management of occupational exams for employees. The specific objective is to address a significant increase in the number of occupational examinations resulting from a change of the health services supplier faced by Epsilon [3] company, Brazil. This increase in exams led to substantial cost escalations, with a surge of 149% in the annual number of exams.

To comprehensively analyze this issue, the study adopts an empirical approach that combines qualitative and quantitative data collection methods. The research is structured based on sequential steps, including documentary analysis, data collection and a detailed case study. The documentary analysis involves assessing the relevant information gathered from PCMSO and PPRA. The data collection phase focuses on obtaining comprehensive data on the number of occupational exams conducted for each job function to establish a baseline.

Finally, a detailed case study is undertaken to analyze and evaluate the impact of various factors on the management of occupational exams. This approach allows for a systematic analysis of the current state, identification of improvement areas, implementation of targeted changes and monitoring of outcomes. The end goal is to optimize the process of occupational exams, leading to more efficient resource utilization and cost reduction.

This study makes several valuable contributions. It adds to the existing body of knowledge by bridging the gap between lean, six sigma and occupational exam management. The results and recommendations generated from this research can inform organizations in effectively addressing the challenges posed by increased occupational exams, leading to improved efficiency, cost savings and compliance with regulatory requirements. In addition, the research outcomes have the potential to benefit organizations facing similar issues in managing occupational exams by providing practical insights and a replicable framework for improvement.

2. Literature review

2.1 Lean six sigma

Lean manufacturing, originating from the Toyota Production System, is a groundbreaking Japanese management model characterized by minimal inventory and high flexibility. The concept emerged in the aftermath of the Second World War, when Japanese companies faced the challenge of achieving efficiency levels comparable to Ford that was known for its low waste and cost-effective operations. These circumstances compelled organizations to align their actions with the principles advocated by lean manufacturing (Barreto, 2012), which consequently became a guiding principle for activities aimed at delivering customer value and eliminating waste (Santos *et al.*, 2020).

The concept of *Six Sigma* was introduced in 1980 by Bill Smith at Motorola Corporation, aiming to reduce errors and defects through the application of the DMAIC methodology (Popa *et al.*, 2005). DMAIC refers to a data-based life cycle approach that ensures an organized, logical and efficient sequence of operations in project management. Its objective is to identify, quantify and minimize sources of process variation (De Mast and Lokkerbol, 2012; Sokovic *et al.*, 2010) through the utilization of statistical quality tools for data collection and analysis that facilitates sustainable decision-making in process-related inquiries.

According to George (2003), merging LSS methodologies is crucial for reducing costs and complexity. While lean focuses on process speed and capital reduction, six sigma alone may not provide the statistical control required. Alternatively, the objective of LSS is to minimize waste, enhance performance and contribute to customer satisfaction (Popa *et al.*, 2005). It is crucial for all individuals within an organization to understand and implement concepts of this methodology, which can be regarded as a business strategy (Endler *et al.*, 2016). By addressing hidden costs of complexity, LSS ensures engagement from all stakeholders, enabling the establishment of a range and quality without compromising speed and cost (George, 2003). Moreover, the combination of lean principles with the DMAIC approach, as advocated by Voehl *et al.* (2010), enables organizations to tackle process inefficiencies systematically, improve quality and deliver sustainable results across a wide range of projects and initiatives.

The integration of LSS principles, along with the DMAIC approach, holds immense importance in the realm of occupational safety and health, as well as the management of occupational exams. By applying LSS principles, organizations can identify and eliminate potential hazards, reduce workplace accidents and enhance the overall safety culture. The systematic DMAIC process allows for the measurement and analysis of safety-related data, enabling organizations to pinpoint root causes of occupational risks and design effective interventions. In addition, LSS and DMAIC provide a structured framework to improve the management of occupational exams, ensuring accuracy, efficiency and reliability. By leveraging LSS and DMAIC in occupational safety and health, as well as exam management, organizations can create safer work environments, protect employee well-being and ensure the integrity and effectiveness of occupational examinations.

2.2 Health and safety requirements in Brazil

The promotion of occupational safety and health is of paramount importance in the labor environment. In Brazil, the necessary requirements and conditions for workplace safety and health are stipulated in the legal document called *Norms Regulated (NR)* that was approved in 1978 by the Ordinance No. 3,214 of the Ministry of Labor (Ministério do Trabalho, 1978). This central law establishes standards and mandates compliance for the implementation of programs and services dedicated to occupational health and safety (Silva and Santos, 2014).

However, it was not until May 18th, 1995, that Brazil officially ratified the Convention 161/85 of the International Labor Organization, signaling a pivotal shift in the approach to labor environment risks and workers' health. This convention prescribed that companies adopted an integrated approach to identifying and addressing such risks, moving away from isolated efforts. To ensure compliance with this convention, Brazil took a proactive step a year prior, in December 1994, by issuing SSST Ordinance No. 24. This ordinance mandated that all employers and institutions employing workers assume the responsibility of developing and implementing specific programs to meet the convention's requirements. These programs include the PPRA under NR 9 and the PCMSO outlined in NR 7 (Ministério do Trabalho e Emprego, 2013; Ministério do Trabalho e Emprego, 2016).

The PPRA plays a crucial role in managing occupational risks and ensuring health and safety of workers in Brazil. The program encompasses various stages, including anticipation, recognition, evaluation and definition of control measures for environmental risks present or potentially present in the work environment. The risks that can pose a threat to the well-being of workers are typically referred to as physical, chemical and biological hazards. The PPRA aims to manage these risks effectively through systematic planning and implementation. It establishes guidelines for identifying and assessing risks, determining appropriate control measures and monitoring their effectiveness.

To facilitate the evaluation process, the NR provides further guidance by detailing two crucial elements of the risk management process: tolerance limits (TL) and levels of action (LA). The TL represents concentration or intensity thresholds that are carefully determined based on the nature and duration of exposure to a particular risk. They represent the maximum or minimum levels at which the risk is deemed acceptable without causing harm to the employee's health throughout their working life. Compliance with these limits ensures that the workplace maintains a safe environment for workers (Ministério do Trabalho e Emprego, 2014).

Complementing the TL, the LA serve as trigger points for implementing preventive measures when risk exposures approach or surpass the established TL. It is essential to initiate proactive actions beyond the LA to minimize the likelihood of occupational risks exceeding the acceptable limits. These preventive actions encompass various strategies, including periodic monitoring of exposures, providing relevant information to workers and implementing appropriate medical controls. By promptly addressing risks once they approach the LA, employers can effectively mitigate potential harm to their employees

(Ministério do Trabalho e Emprego, 2016). These collective efforts ensure that risks are proactively managed and occupational health and safety standards are upheld.

Based on the recognition and evaluation of risks described in the PPRA, the establishment and implementation of the PCMSO is vital. This program, in accordance with the guidelines outlined in NR 7, sets forth the minimum parameters for occupational and clinical examinations, as well as their recommended frequency for employees. Its primary objective is to detect potential risks and factors contributing to employee illness, while defining measures for prevention, elimination or reduction (Ministério do Trabalho e Emprego, 2013).

Alongside NR 7 and NR 9, it is also important to consider NR 15, a regulatory standard that evaluates and classifies unhealthy conditions. This standard assesses activities that have the potential to cause diseases in exposed workers, such as those involving gammagraphy radiation and gamma-type ionizing radiation. These activities can pose significant health risks within a certain distance (Saliba and Corrêa, 2022). A critical aspect of implementing the NR 15 is the classification, planning and control of activities to ensure ongoing compliance and to dynamically measure adherence (Saliba and Corrêa, 2022).

To effectively implement these programs, it is crucial to identify occupational risks through technical site visits, employee interviews and quantitative risk monitoring. This comprehensive approach ensures compliance with legislation, prevents underestimation or overestimation of actions and allows for proper allocation of costs associated with managing these programs (SESI, 2007; Gueiros, 2006). By following this systematic approach, organizations can guarantee the successful implementation of these programs and promote a safe and healthy work environment for employees.

2.3 Lean Six Sigma 4.0

LSS 4.0 concerns the integration of tools, methodologies and principles of LSS with I4.0 technologies, focusing on operational improvements in production processes (Nascimento *et al.*, 2020). This integration, called LSS 4.0, uses I4.0 technologies, such as big data analytics, artificial intelligence, cloud computing, Internet of Things, digital twin, 3D printing and interoperability to support and optimize the implementation of the Lean principles linked with the DMAIC methodology in favor of operational excellence (Antony *et al.*, 2023). Also, for example, the use of I4.0 technologies to digitalize lean tools, such as value stream mapping (Fontoura *et al.*, 2023), Ishikawa diagram (Sal *et al.*, 2021), poka yokes (Chen *et al.*, 2023), among others.

The implementation and maturation of LSS 4.0 in industrial organizations require significant adaptation and transformation, with culture being a key factor (Arcidiacono and Pieroni, 2018). Successful adoption of emerging technologies relies on prior adaptation of processes and people, according to the cultural determinism theory (Jackson and Philip, 2010). However, these sociocultural changes can create conflict regarding the effort needed to achieve success in LSS 4.0 implementation (Antony *et al.*, 2023; Citybabu and Yamini 2023a). Standardizing data modelling and processes is critical to ensuring a sustainable and interoperable adoption of LSS 4.0, making them key success factors for real and scaling-up implementation (Caiado *et al.*, 2021; de Mattos Nascimento *et al.*, 2024). Data and process interoperability are crucial for accurately representing the LSS 4.0 application domain in an open, scalable and standardized manner, benefiting the digital supply chain and operations management (Bueno *et al.*, 2023).

2.4 Digital process interoperability

Interoperability is the ability of systems, processes, catalogues and knowledge to be standardized and automated in favor of digital operations and supply chain resilience (Caiado *et al.*, 2021). Within this context, object-oriented information modeling and standardization through neutral interoperability formats are one of the premises for the digital transformation of processes (de Mattos Nascimento, 2017). In this way, providing the modeling of the processes and the data object that permeate them, all necessary integration for the value flow of information is specified, called information delivery manuals (IDMs), in a standardized and accessible manner (Pinheiro *et al.*, 2018; Calvetti *et al.*, 2023). The construction of an IDM is essential to provide improvements and standardize information flows linked to work processes, resulting in exchange information requirements (EIRs) that specify each necessary object-oriented information to validate a stage of the work process and allow it to be translated by neutral standards (Pinheiro *et al.*, 2018), such as the industry foundation classes to import and export information in software that an organization needs and standardize data contract with digital operations and supply chains (Eastman *et al.*, 2010; Andriamamonjy *et al.*, 2018).

3. Methodology

This research uses an exploratory approach to assess the application of LSS principles, along with the DMAIC methodology and I4.0 technologies to digital process, in managing occupational exams for employees. The specific objective of this study was to address a significant increase in the number of occupational examinations resulting from a change in the health services supplier, brought to our attention by Epsilon [4] company. Following the transition to a new supplier, the company witnessed a significant and noteworthy surge of 149% in the annual number of occupational exams, resulting in substantial cost escalations. To facilitate a comprehensive analysis of the issue, we adopted a mixed-methods approach that combines both qualitative and quantitative data collection (Tortorella *et al.*, 2020). Hence, this study was structured based on the following sequential steps:

- *Literature review*: An in-depth investigation of JCR journal articles about concepts, methods and technologies to operational excellence concerning LSS 4.0 was presented.
- *Documentary analysis*: A thorough assessment of the PCMSO and PPRA was conducted to gather relevant information.
- *Data collection*: Comprehensive data on the number of occupational examinations conducted for each job function was collected to establish a baseline.
- *Case study*: A detailed case study was undertaken to analyze and evaluate the impact of the studied factors on management of occupational exams.

The analysis of documents focused on the period from January 2017 to January 2018, when a significant rise in the number of occupational examinations was observed for employees engaged in activities involving chemical risk. These exams are mandated by the NR 7, which sets the parameters for the biological control of occupational exposure, requiring them to be conducted semiannually (Ministério do Trabalho e Emprego, 2014).

The study encompassed the examinations of employees who are based at the main office in Brazil, while excluding specific categories such as exams conducted for job function changes, return to work and dismissal. These exclusions were made because the work environment explored in this study did not involve biological risks and thus did not require the assessment of ergonomic and accidental risks, as mandated by NR 9 (Ministério do Trabalho e Emprego, 2016). Furthermore, to evaluate costs accurately, certain expenses were not taken into consideration, such as reimbursement for employee travel during exams and clinical costs incurred when exams were conducted in a different city. The only expenses considered in the study were the actual costs of the occupational examinations, as established by Suppliers A and B.

To address the identified issue of the increased number of occupational exams, this study proposes a solution through the application of LSS using the DMAIC methodology. Combining these two approaches makes it possible to systematically analyze the current state of the issue, identify areas for improvement, implement targeted changes and monitor the outcomes. This, in turn, permits to optimize the process of occupational exams, resulting in more efficient utilization of resources and reduction of unnecessary costs. Figure 1 provides a visual representation of the essential stages of the proposed methodology, effectively illustrating the comprehensive and systematic nature of the exploration process. It highlights the structured approach undertaken to achieve the desired improvements in a clear and concise manner.

To validate the appropriability and functionality of the proposed methodology, we applied it to the specific case of Epsilon diligently following the outlined phases, which are elaborated below:

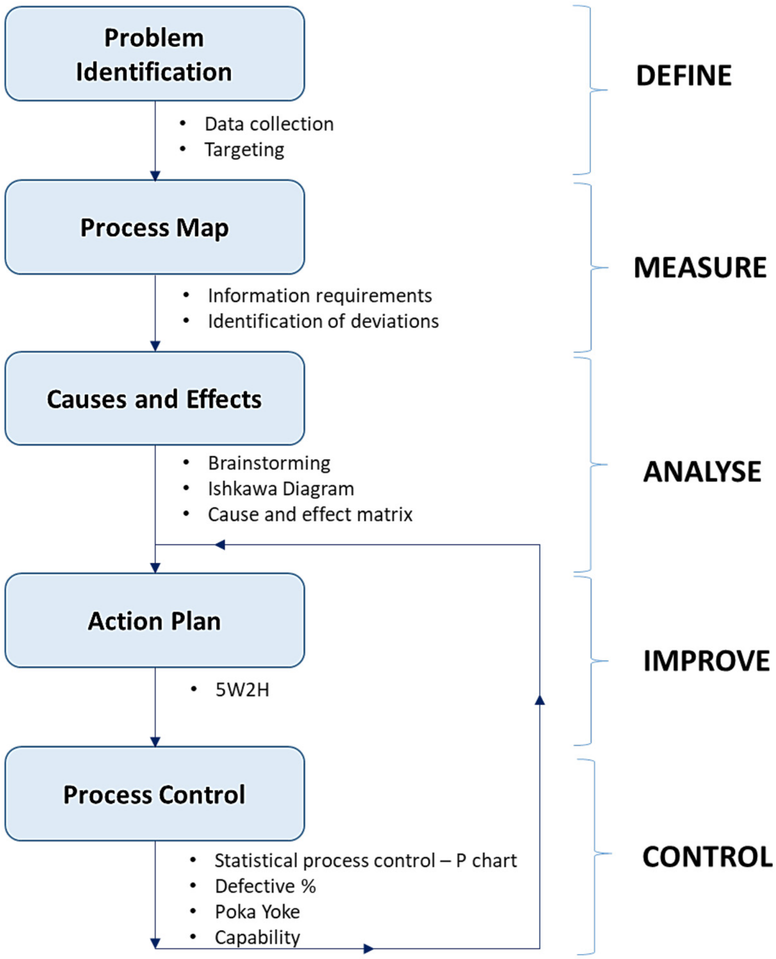

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Figure 1. The DMAIC method to reduce the number of occupational exams

- *Define phase:* A comprehensive diagnosis of the situation was conducted both before and after the change of the health service supplier. This diagnosis specifically focused on the collection of the number of occupational exams conducted annually, as prescribed by the PCMSO. Subsequently, a scrupulous assessment was made to quantify the costs associated with these exams, taking into account the prices set by the suppliers for each exam, as well as the frequency of exams throughout the year. To better comprehend this aspect, two key indicators were established: the "rate of increase of exams" and the "rate of increase of cost." These indicators served to provide a clear understanding of how the number of exams and associated expenses have evolved over time.
- *Measure phase:* The quality, health, safety and environment (QHSE) unit, as well as human resources department, were involved to develop a detailed process map. This map was created using the business process modeling notation and served to illustrate the sequential flow of activities, as well as the necessary information requirements for their execution.

During the development of the process map, particular emphasis was placed on evaluating the process parameters based on the legal requirements outlined in NR 7, NR 9 and NR 15. These regulations establish guidelines and standards for occupational health, safety and environmental practices. By aligning the evaluation criteria with these legal requirements, the process map ensures compliance and adherence to relevant regulations:

- *Analyze phase:* A thorough examination of process deviations took place, focusing on the information requirements and associated parameters. The analysis was visualized using a *Pareto graph*, which provided valuable insights into the most significant deviations. Subsequently, the QHSE department organized a brainstorming meeting to further investigate and identify the primary causes behind these deviations.

During the meeting, the *Ishikawa diagram*, also known as the fishbone diagram, was used to systematically map out the potential causes of the identified deviations. In addition, a *cause-and-effect matrix* was used to assess the relationships between the identified causes and the observed deviations. This matrix played a vital role in pinpointing the root cause of the deviations, offering a focused and targeted approach to address the underlying issues.

- *Improve phase:* The *5W2H action plan* [5] was used to define the specific actions required to tackle the root cause effectively. Once the actions were determined, they were implemented as part of the improvement process. Subsequently, updates were made to the PCMSO, ensuring that it reflected the changes and adjustments made in response to the identified issues. This included redefining the necessary exams and incorporating any modifications required.

In addition, the process map underwent resizing to accommodate the changes implemented during the improve phase. This ensured that the map accurately reflected the updated workflow and activities resulting from the improvement actions. The resizing of the process map provided a clear visual representation of the optimized process, facilitating better understanding and communication within the organization:

- *Control phase:* This phase spanned from April 2018 to January 2019. The QHSE department diligently conducted verification of the occupational exams performed by employees. By analyzing the obtained results, it became possible to assess the processing capacity both before and after the implemented improvements. To monitor the proportion of defective exams and evaluate the process's capacity, the QHSE unit leveraged the Minitab software. This powerful tool enabled accurate tracking of defective exams over time, allowing for real-time monitoring of quality performance. By using Minitab, the QHSE department was able to proactively identify any potential issues, make data-driven decisions and ensure the ongoing success of the improved process.

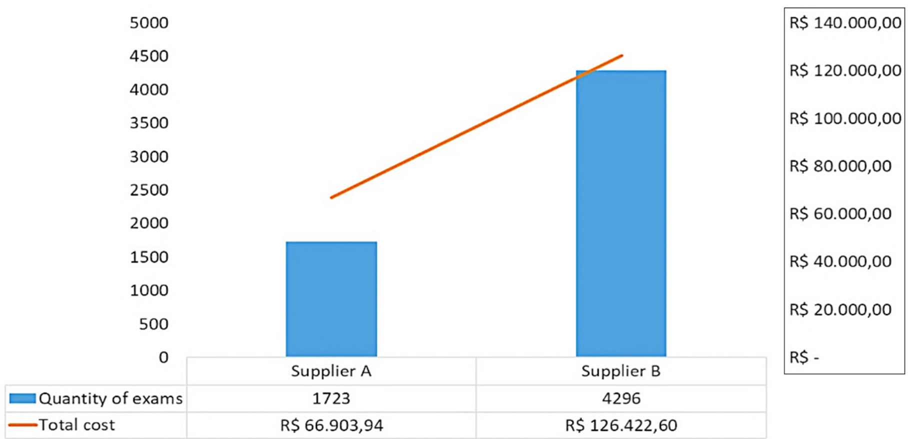
To promote transparency and widespread visibility of the project, the results were meticulously documented and shared through an A3 format. These A3 reports were prominently displayed on company murals, allowing employees to stay informed and engaged with the improvement efforts. In addition, a comprehensive presentation was delivered to the Board of Directors, providing a comprehensive overview of the project's progress and outcomes. By adopting these practices, the team ensured efficient collaboration, effective communication and widespread awareness of the project's objectives and achievements throughout the organization.

4. Results and analysis

This section presents a thorough analysis of the results obtained from the application of LSS using the DMAIC methodology to the case study of Epsilon. The results are presented and discussed in accordance with the different phases proposed in the methodology section, offering a step-by-step guide into the improvement journey.

4.1 Define phase

Based on an in-depth analysis of the occupational examinations provided by Suppliers A and B to Epsilon from January 2017 to January 2018, significant insights were gained regarding the annual growth of the number of occupational exams and their corresponding costs (see Figure 2). During this period, it was estimated that Supplier A would have conducted 1,723 occupational exams annually. However, following the change of the health service supplier in July 2017, the forecasted number of exams significantly increased to 4,296 per year (approximately 149.39%).



Source: Authors' own creation

Figure 2. Occupational exams quantity and cost comparison – Supplier A vs B

Consequently, the associated costs also experienced a substantial surge, rising by 89% annually. The estimated cost of exams for Supplier A was calculated to be R$66,903.94, and for Supplier B, the projected cost reached R$126,422.60, equivalent to €15,561.86 [6] and €29,405.90, respectively, which suggests an 89% surge in costs. These findings reveal the considerable impact of the change in health service supplier on both the number of exams conducted and the subsequent financial burden.

4.2 Measure phase

To gain a comprehensive understanding of the workflow and activities involved, a detailed process map was developed, illustrating the step-by-step sequence of activities. This process map, depicted in Figure 3, provided a visual representation of the various stages and interactions within the process of occupational examination. In addition, the corresponding information requirements were identified for each activity. These information requirements were outlined in Table A1 (Appendix 1), detailing specific data, documents or inputs necessary for each step of the process.

After identifying the necessary information, several parameters were evaluated, but it was found that certain criteria did not meet the legal requirements. These deviations included the following:

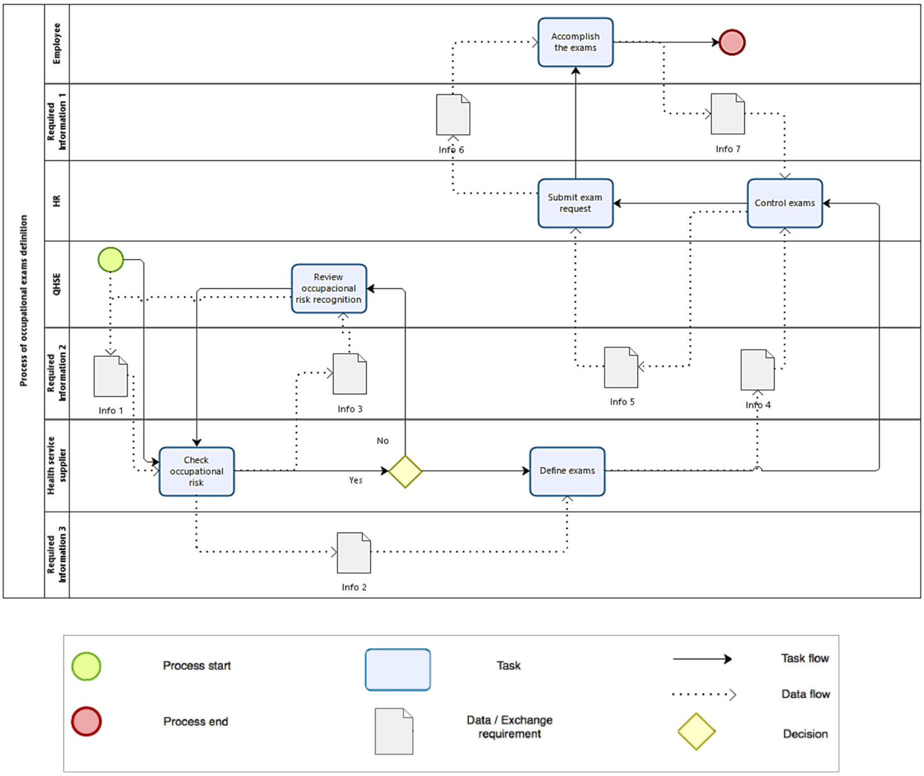


Figure 3. Information delivery manuals (IDM) AS IS to digitalize the occupational exams process

Source: Authors' own creation

- inappropriate homogeneous exposure group (HEG);
- inappropriate exposure assessment methodology for chemical risks;
- unidentified concentrations of vapor organic compounds and vibration risks; and
- rejection of metal fumes, metal dust and BTX (benzene, toluene and xylene) concentration data for examination definition.

These deviations were quantified and are illustrated in the Pareto chart (Figure 4), highlighting the most significant issues. Among them, the unidentified concentration category had the highest occurrence rate, totaling 201 occurrences.

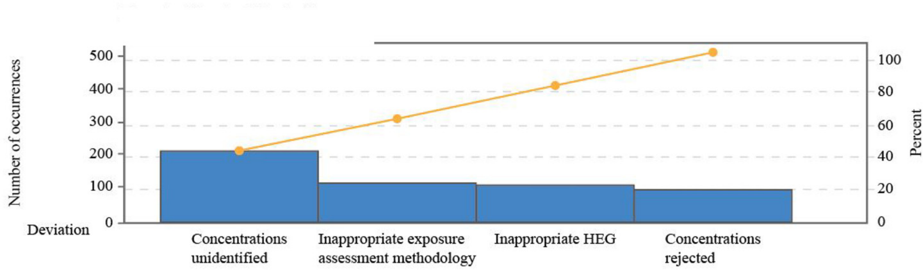
4.3 Analyze phase

Following this stage, the QHSE team organized a brainstorming meeting to identify the causes of deviations using the Ishikawa diagram, also known as the fishbone diagram (Figure 5). This collaborative session allowed for a structured exploration of potential causes across different categories, facilitating a systematic approach to problem-solving.

Using the Ishikawa diagram as a basis, a cause-and-effect matrix (Table A2, Appendix 2) was developed to prioritize actions that would address the most significant effects. The matrix aimed to identify the causes that, when eliminated, would lead to a reduction in the highest number of associated impacts.

In the matrix, the first column represents the causes that contributed to the deviations, while the top row indicates the effects along with their assigned importance weights (ranging from 5 to 10) as determined by the team. To establish the correlation between causes and effects, the team assigned correlation values based on the following criteria: (0) no correlation, (1) poor correlation, (3) moderate correlation and (5) strong correlation. The final column in each row of the matrix presents the cumulative values obtained by multiplying the correlation level of each cause by the weight of the effect and summing them up.

Interpreting the results, the highest value in the last column of the matrix indicates the top priority, as it represents a strong correlation with the identified effects. By implementing corrective actions to address the root cause associated with this highest value, the largest number of effects can be eliminated. In this case, out of the eight identified effects, the action



Number of occurrences	201	99	84	82
Percent	43.1	21.2	18.0	17.6
Cum %	43.1	64.4	82.4	100.0

Source: Authors' own creation

Figure 4. Pareto chart of deviation

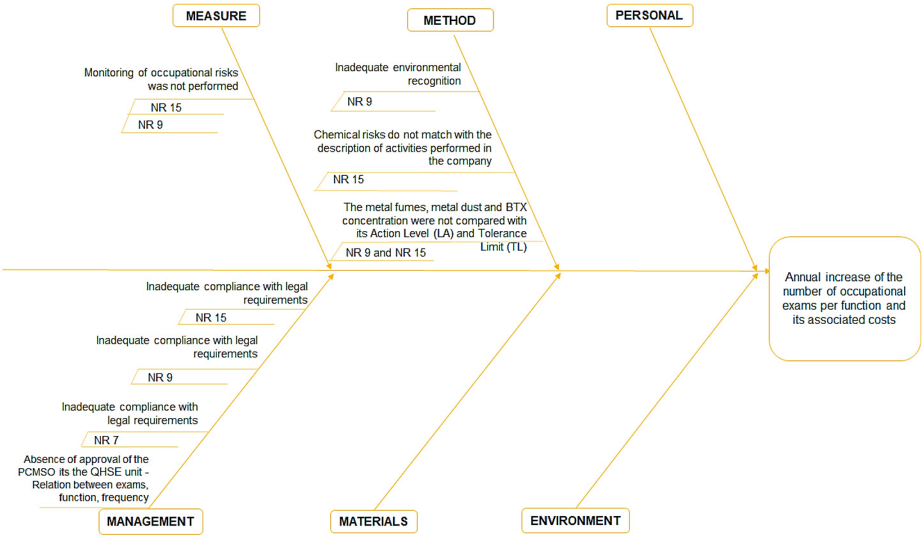


Figure 5.
Ishikawa diagram

Source: Authors' own creation

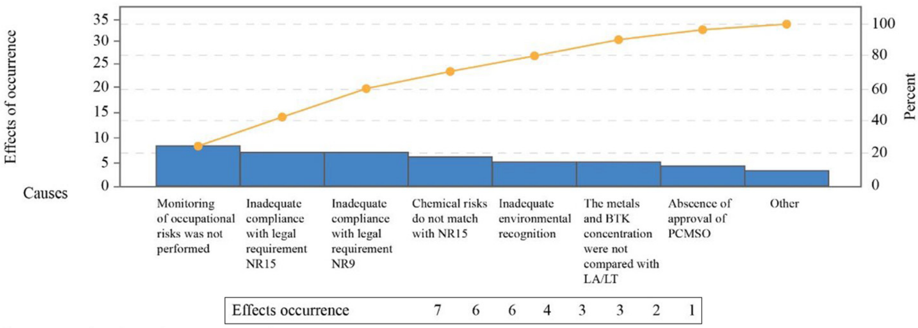


Figure 6.
Pareto chart of cause occurrences

Source: Authors' own creation

implementation would have resolved seven, as observed in the Pareto chart presented in Figure 6.

The findings from our cause analyses support the research conducted by Silva and Santos (2014) regarding the lack of coherence between occupational risks in the workplace and recommended occupational exams in the PCMSO. In their study, 60.9% of the examined companies reported this inconsistency. Similarly, Miranda and Dias (2004) found this lack of coherence in 64.21% of the analyzed PCMSOs from 28 companies. Specifically, 50% of these discrepancies were associated with occupational exams for physical risks, 7.1% with exams for chemical risks and 7.1% with exams for biological risks in the workplace. In companies with inconsistencies in their PCMSO, 57.1% were related to the conducted exams, 21.4% to their periodicity, 17.9% to clinical exams performed, 17.9% to the Occupational Health Medical Certification [7] (ASO) process and 3.6% to data registration in individual clinical records. Miranda and Dias (2004) also discovered that 92.9% of companies had inconsistencies in their PPRA. Among these, 42.9% of firms exhibited discrepancies in risk recognition, while 39.3% had inconsistencies in quantitative monitoring.

To recapitulate, both the research conducted by Silva and Santos (2014) and Miranda and Dias (2004), as well as the findings from our cause analyses highlight the lack of coherence between occupational risks and recommended occupational exams in the PCMSO, as well as inconsistencies within the PPRA and PCMSO programs in various companies. These discrepancies encompass aspects such as risk recognition, quantitative monitoring and the performance of specific exams, which have implications for ensuring the health and safety of workers in the workplace. The results of our analysis particularly indicate that misclassification of vapor organic compounds and the lack of their monitoring resulted in a significant increase in related exams. Furthermore, the absence of monitoring for vibration risk led to the inclusion of pulse X-ray exams, as the concentration measurements to determine the level of employer exposure (NR 15 and NR 9), were not performed. In addition, the concentrations of metallic fumes, metallic dust and BTX vapors were below the LA, and they did not require medical control. However, these circumstances were not considered by Supplier B who was assigning occupational exams associated with these risks.

4.4 Improve phase

During the improvement phase, the IDM process mapping was used to identify inefficiencies and bottlenecks in the current process. This methodology helped propose and validate an optimized IDM process to enable software and hardware solutions to connect in an LSS 4.0 digital process. The team also conducted analyses to optimize occupational exams while modeling information from digital packages. EIRs were modeled by considering classes and attributes, and this helped establish the minimum and optional digital requirements for implementing LSS 4.0 in industrial organizations to manage occupational health examinations. The information necessary for each stage of the digital process was stratified and standardized, which led to creating a procedure specific to a digital process with information packages (EIRs) and standardized sequences.

Thereby, specific actions and solutions were designed to address the identified issues and optimize the process. These actions were carefully planned and executed, leveraging the expertise and collaborative efforts of the project team. Specifically, the QHSE team identified the primary corrective actions for addressing the root cause in a systematic manner. To facilitate the implementation of these actions, an action was developed and is presented in Table 1. The action plan was developed using the 5W2H tool, which provides a clear framework for addressing key aspects of the plan. The first W outlines the specific actions to be taken, the second W explains the rationale behind those actions, the third W identifies the locations where the actions will be implemented, the fourth W designates the responsible individuals for each action, the fifth W establishes the timeline for completion, the first H outlines the methods or procedures for executing the actions, and the second H addresses the associated costs, either in terms of labor hours worked or the monetary value in Brazilian Real (and in EUR). This comprehensive action plan aimed to drive the necessary process improvements and included defined tasks and deadlines for each team member. The QHSE coordinator effectively communicated the action plan to the project team, general management and the board of directors to ensure alignment and commitment to its implementation. The action plan was implemented from July 2017 to January 2019.

Table 1.
Action plan 5W2H

Item	What	Why	Where	Whom	When	How	How much
1.0	Obtain quantitative monitoring of environmental risks						
1.1	Update recognition of environmental risks by GHE	Inadequate environmental assessment	Main office	Work safety technician	21/07/2017 until 08/08/2017	Field visit and interview with employees	LH* Work safety technician
1.2	Classification of agents according to NR 15	Chemical risk assessment does not comply with legal requirements of NR 15	PPRA	Work safety engineer	21/08/2017	Based on NR 15	LH Work safety engineer
1.3	Perform quantitative monitoring of occupational risks	Some occupational risks do not comply with NR 15	Main office	External consulting company	19/08/2017 30/08/2017 and 14/09/2017	By involving monitoring agents	R$ 6,000.00 (approximately €1,400)
1.4	Compare the monitored concentrations with the TL and LA by HEG	The metal fumes, metal dust and BTX concentration were not compared with its TL and LA. Inadequate compliance with legal requirements of NR 15 and NR 9	PPRA	Work safety engineer	14/09/2017	Based on NR 15 and NR 9	LH Work safety engineer
1.5	Update the PPRA	Inadequate compliance with legal requirements of NR 15 and NR 9	PPRA	Work safety engineer	26/02/2018	Based NR 15 and NR 9	LH Work safety engineer
2.0	Redefine exams of the PCMSO based on PPRA	Inadequate compliance with legal requirements of NR 7	PCMSO	Health service supplier and work safety technician	15/12/2017 until 11/03/2018	Based on PPRA	LH Work safety engineer; LH Occupational health physician
3.0	Evaluate ASO	Absence of approval of the PCMSO by the QHSE unit – relationship between exams, function, and frequency	ASO and PCSMO	Work safety technician	01/04/2018 until 31/01/2019	Comparing the exams done in the ASO with the exams defined in the PCMSO	LH Work safety technician
4.0	Develop operational procedures	To ensure that the exam definition process is a part of the integrated management system of the company	Company management system	Work safety engineer	31/09/2019	Through systematic process of procedure development	LH Work safety engineer

Note: **LH = labor hours*
Source: Authors' own creation

4.5 Control phase

Finally, in the control phase, measures were put in place to ensure the sustained success and continued improvement of the optimized process. Robust monitoring systems were implemented to track performance, and appropriate control mechanisms were established to mitigate any potential deviations or setbacks.

Thus, during this period, an on-site assessment of environmental risks was conducted, along with interviews with employees. Based on this assessment, the HEG was defined according to the exposure to environmental risks. The risks that could be monitored included chemical risks (organic compound vapors, metallic dust and metallic fumes) and physical risks (vibration and noise). The chemical products were classified according to NR 15 (based on the types of chemicals present in the workplace and their LT). Vibration was also classified according to NR 15, which establishes the daily exposure limit for occupational vibration.

Accordingly, to monitor these risks, an external consulting company was hired at a cost of R$6,000 (approximately €1,400). The monitoring results showed that the levels of metallic fumes, metallic dust, BTX vapors, vibration and organic compound vapors were below the permissible exposure limits (LA), as specified in NR 9. Therefore, no further medical control was required for these risks. However, the levels of manganese and noise exceeded the permissible limits, indicating the need for occupational exams to be conducted.

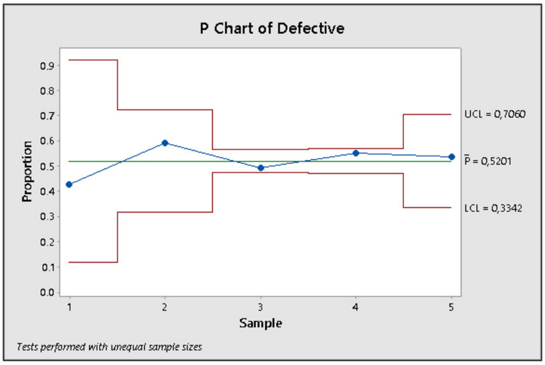
To assess the characteristics of the occupational exams process prior to the implementation of the action plan, a P-type statistical control chart was employed as a means of comparison. Figure 7 illustrates the relationship between the total number of exams conducted within each HEG and the number of exams identified as defective prior to the implementation of the action plan.

The data covers the period from August 2017 (when the service provider was changed) to March 2019 (prior to the implementation of corrective actions). The P chart clearly indicates that the process is both under control and stable, with no points exceeding the lower control limit (LCL) or upper control limit (UCL). This suggests a well-regulated process. However, the proportion of defective exams was found to be 52.01%, indicating a low process capability corresponding to a sigma level of −0.05, resulting in 520,093 defects per million.

Data Input for the P chart

GHE (subgroup)	*Exams Performed*	*Defectives*
2	14	6
4	54	32
7	1.116	550
8	891	490
9	65	35

Process Characterization	
Number of subgroups	5
Average subgroup size	428
Total items tested	2.140
Number of defectives	1.133
Process Capability	
% defective	52,01
Process Z	−0,05
PPM Defect	520.093



Source: Authors' own creation

Figure 7. P chart of defectives and process characterization before improvements

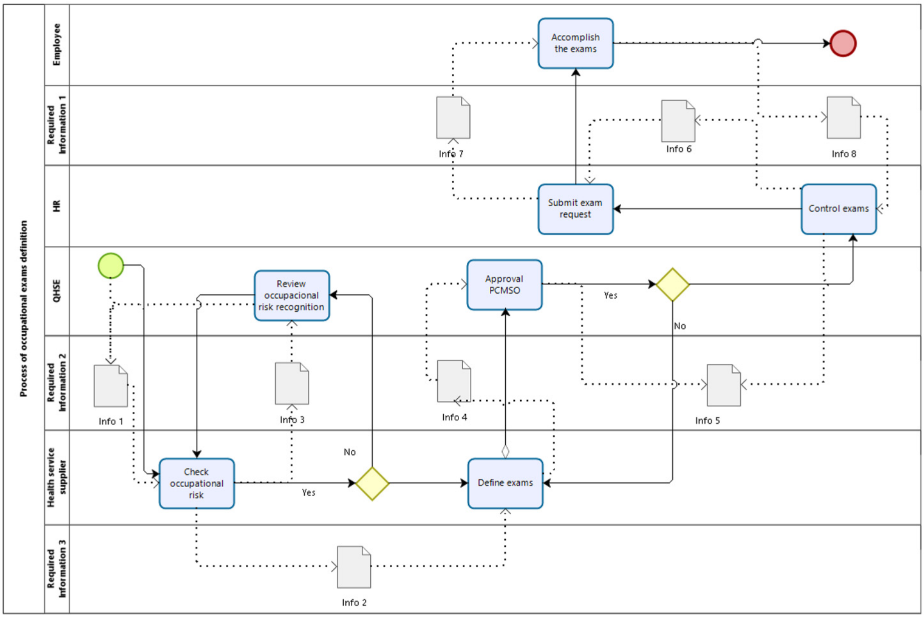


Figure 8.
IDM digital process map after improvements

Source: Authors' own creation

In March 2018, employees commenced their occupational exams in line with the revised PCMSO. The QHSE team conducted a thorough review of the employees' ASO to ensure compliance with the specified exam types, frequencies and job functions. During this process, defective exams were identified. As a result, the QHSE department integrated the approval stage of the PCMSO into the process map (Figure 8) as a poka-yoke detection mechanism. This ensured that the health-care service provider would receive guidance from

Data Input for the P chart		
HEG (subgroup)	*Exams Performed*	*Defectives*
2	8	0
4	22	0
7	660	0
8	443	1
9	30	0

Process Characterization	
Number of subgroups	5
Average subgroup size	232.6
Total items tested	1163
Number of defectives	1
Process Capability	
% defective	0.09
Process Z	3.13
PPM Defect	860

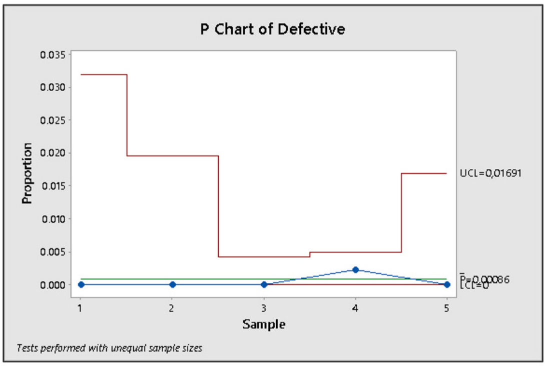


Figure 9.
P chart of defectives and process characterization after improvements

Source: Authors' own creation

the QHSE unit via email, guaranteeing the adequacy of exams (if necessary) before these are taken by employees.

Figure 9 illustrates the progress made in the occupational exam process after the implementation of improvements. It depicts the relationship between the total number of exams conducted by HEG and the number of exams identified as defective. The data spans from 01/04/2018 to 31/01/19, representing the period when employees began undergoing exams in accordance with the updated process map and PPRA.

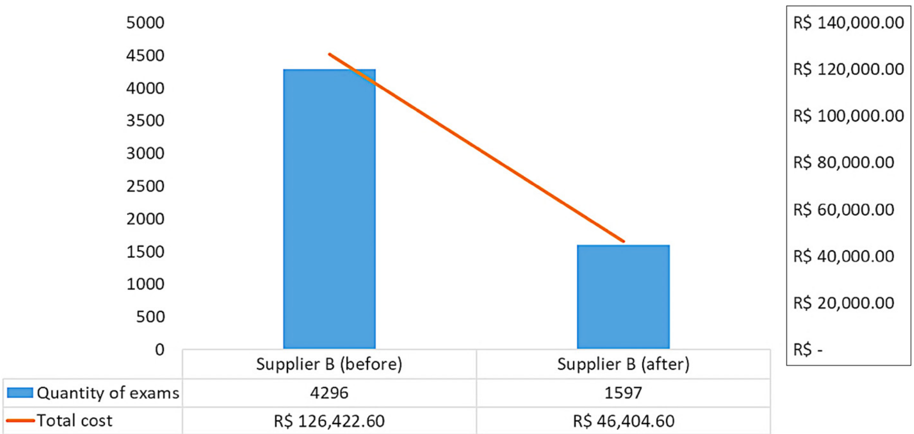
The P-type statistical control chart displayed in Figure 9 provides valuable insights into the stability of the process. It shows that the process is under control and stable, as evidenced by the absence of data points surpassing the LCL and UCL. This indicates that the variations in the process are primarily due to natural causes.

Although one defective exam was detected during this period, the overall results of the study were considered satisfactory. The proportion of defectives decreased significantly to a mere 0.09%. This reduction highlights the effectiveness of the implemented changes in enhancing the stability and reliability of the process. It demonstrates that the improvements contributed to a higher level of process control and a reduction in its variability.

The achieved sigma level of $Z = 3.13$ further reinforces the positive impact of the implemented actions. This sigma level signifies a high level of process capability, with only 860 defects per million exams conducted. These results reflect the successful outcome of the implemented improvements, leading to a more efficient and reliable occupational exam process.

When considering the future scenario where all employees undergo occupational exams, the estimated annual reduction in exams is projected to be from 4,296 to 1,597 (62.82%). This substantial reduction not only signifies the streamlining of the process but also emphasizes the potential for significant cost savings. The estimated cost reduction is expected to reach 63.4%, from R$126,422.60 (€29,405.90) to R$46,404.60 (€10,793.71), as shown in Figure 10.

These findings are consistent with the work of Saliba and Corrêa (2022), who emphasized the importance of using LSS methodologies in optimizing processes and achieving cost savings. In addition, the study aligns with the research by SESI (2007) and Gueiros (2006), who emphasize the significance of identifying occupational risks through technical site visits, employee interviews and quantitative risk monitoring.



Source: Authors' own creation

Figure 10. Comparison of occupational exam quantity and cost before and after improvements

Furthermore, the development of an operational procedure by the QHSE department, along with the training provided to employees responsible for process activities, has played a crucial role in sustaining the systematic approach implemented in the organization. This aligns with the recommendations of several scholars, including Fischer *et al.* (2020) and Mor *et al.* (2019), who highlight the importance of standardizing procedures and providing adequate training to ensure the long-term success of process improvements.

In conclusion, the results of this study underscore the effectiveness of the DMAIC methodology and the LSS approach in driving positive changes in the occupational exams process. The significant reduction in the number of exams and associated costs demonstrates tangible benefits of implementing improvements. Moreover, the development of an operational procedure and training of employees support the sustainability of the implemented changes and foster a culture of continuous improvement within the organization.

5. Conclusion

This research used an exploratory approach to assess the application of LSS 4.0 approaches, along with the DMAIC methodology, in managing occupational exams for employees. The study aimed to address the significant increase in the number of occupational examinations resulting from a change in the health services supplier, confronted by Epsilon company. The findings of this research have important implications for organizations facing similar challenges in managing occupational exams.

Specifically, the research revealed several key findings. First, the change in health service supplier led to a substantial increase of 149% in the annual number of occupational exams, resulting in significant cost escalations. This highlights the importance of effectively managing and optimizing the process of occupational exams to reduce unnecessary costs.

Second, the analysis of process deviations and information requirements uncovered several areas of improvement. Deviations related to inappropriate homogeneous group of exposure, inappropriate exposure assessment methodology for chemical risks, unidentified concentrations of vapor organic compounds and vibration risks and rejection of certain data for examination definition were identified. These deviations were quantified and prioritized using Pareto analysis and cause-and-effect matrix, allowing for a focused and targeted approach to address the root causes.

Third, the implementation of improvement actions based on the identified root causes led to significant enhancements in the digital and standardized IDM process of occupational exams. The 5W2H action plan facilitated the implementation of specific actions, and updates were made to the PCMSO to reflect the changes and adjustments. The resizing of the process map provided a clear visual representation of the optimized process, aiding in better understanding and communication within the organization.

Fourth, in the control phase, measures were implemented to ensure the sustained success of the optimized process. Monitoring systems were established to track performance, and control mechanisms were put in place to mitigate deviations. The use of Minitab software enabled real-time monitoring of quality performance, allowing for proactive identification of potential issues.

5.1 Implications

The implications of this research are twofold. First, it provides a practical framework for organizations to manage and optimize the process of occupational exams using LSS 4.0 approaches along with the DMAIC methodology. The systematic approach presented in this study can help organizations identify areas for improvement, implement targeted changes and monitor outcomes, leading to more efficient utilization of resources and reduction of unnecessary costs.

Second, this research contributes to the originality of the field of study by applying the LSS principles and DMAIC methodology specifically to management of occupational exams. While these principles and methodologies have been widely used in various industries, their application of LSS 4.0 framework in the context of occupational exams is relatively novel. By demonstrating their effectiveness in improving the process and reducing costs, this research adds to the existing body of knowledge and opens avenues for further research in this area.

5.2 Limitations

It is important to acknowledge certain limitations of this research. First, the generalizability of the findings may be limited as this study was conducted solely at Epsilon. The unique characteristics of the organization and its specific context may not directly translate to other industries or organizations.

Secondly, the scope of this study focused exclusively on the management of occupational exams related to chemical risks at Epsilon's main office. Other categories of exams and their associated challenges were not considered, potentially restricting the comprehensive understanding of the broader occupational exam management process. Thirdly, the cost considerations presented in this research only accounted for direct exam costs and did not include additional expenses such as employee travel or clinical costs. The financial implications discussed may therefore not encompass the full cost impact of managing occupational exams.

Furthermore, the short timeframe of the study limited the ability to evaluate long-term trends and the sustainability of the proposed improvements over an extended period. External factors such as changing regulations or industry standards were also not considered, which could influence the effectiveness and applicability of LSS principles in different contexts. Finally, the accuracy and potential biases in the data collected from Epsilon's occupational exam records and assessments may introduce certain limitations to the reliability and validity of the findings.

5.3 Future research

Despite the limitations mentioned, the findings of this study provide valuable insights and a starting point for organizations seeking to enhance the management of occupational exams. Further research incorporating a broader range of exams, considering external factors and addressing the identified limitations would contribute to a more comprehensive understanding of this topic. One avenue for future research is to conduct comparative studies across different industries and organizations to assess the generalizability of LSS principles in the context of occupational exams. This would involve examining how different organizational structures, regulatory environments and industry-specific challenges impact the effectiveness of process improvement methodologies.

Likewise, future research can expand the scope of the study to include a broader range of occupational exams, such as medical exams, psychological assessments or physical fitness tests. By considering the unique requirements and challenges associated with each type of exam, researchers can develop tailored approaches that address specific areas of improvement within the exam management process. Long-term studies can be conducted to evaluate the sustainability and long-lasting impact of implementing LSS principles in the management of occupational exams. Such research would provide insights into the continued effectiveness of process improvements over time and help identify any potential barriers or challenges that arise in maintaining the improved processes.

In addition, future research should take into account external factors that can influence the management of occupational exams, such as evolving regulations, emerging technologies or changes in industry standards. By considering these external influences, researchers can better understand how to adapt and apply LSS principles in a dynamic and evolving environment. Overall, future research endeavors should aim to address the identified limitations, explore new avenues for improvement and contribute to the development of best practices in the management of occupational exams. By continuously expanding our knowledge in this area, organizations can optimize their processes, improve employee well-being and ensure compliance with regulatory requirements.

Notes

1. Programa de Controle Médico de Saúde Ocupacional (*português*).
2. Programa de Prevenção de Riscos Ambientais (*português*).
3. The company's name was altered for reasons of confidentiality.
4. *Epsilon* is a multinational provider of inspection, repair, and maintenance services in the oil, gas and energy sector, located in Rio de Janeiro, Brazil. With a focus on excellence and reliability in quality, safety, health, environment, and social accountability, Epsilon aligns its operations with the highest industry standards. The company recognizes the growing demand for highly skilled labor and strives to be a trusted partner capable of executing contracts within stipulated deadlines.
5. The *5W2H action plan* is a management tool used to guide and organize the implementation of a specific project or task by answering seven key questions, each beginning with either "W" or "H": who, what, when, where, why, how, and how much.
6. Based on the average exchange rate of Brazilian Real (BRL) to Euro (€) in 2018: 1 BRL = €0.2326 – the year corresponding to the evaluation of costs associated with the occupational exams. Source: www.exchange-rates.org
7. Atestado Médico de Saúde Ocupacional (*português*).

References

Andriamamonjy, A., Saelens, D. and Klein, R. (2018), "An automated IFC-based workflow for building energy performance simulation with modelica", *Automation in Construction*, Vol. 91, pp. 166-181.

Antony, J., McDermott, O., Powell, D. and Sony, M. (2023), "The evolution and future of lean six sigma 4.0", *The TQM Journal*, Vol. 35 No. 4, pp. 1030-1047.

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.

Ariente, M., Casadei, M.A., Giuliani, A.C., Spers, E.E. and Pizzinatto, N.K. (2016), "Processo de mudança organizacional: estudio de caso do seis sigma", *Revista Da FAE*, Vol. 8 No. 1, pp. 81-92, available at: https://revistafae.fae.edu/revistafae/article/view/377

Barreto, A.R. (2012), "Sistema toyota de produção: lean manufacturing implantação e aplicação em uma indústria de peças automotivas", *Tékhne ε Lógos*, Vol. 3 No. 2, pp. 2-16. Julho, available at: http://revista.fatecbt.edu.br/index.php/tl/article/view/54

Bueno, A., Caiado, R.G.G., de Oliveira, T.L.G., Scavarda, L.F., Godinho Filho, M. and Tortorella, G.L. (2023), "Lean 4.0 implementation framework: proposition using a multi-method research approach", *International Journal of Production Economics*, Vol. 264, p. 108988.

Caiado, R.G.G., Scavarda, L.F., Gavião, L.O., Ivson, P., de Mattos Nascimento, D.L and Garza-Reyes, J.A. (2021), "A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management", *International Journal of Production Economics*, Vol. 231, p. 107883.

Calvetti, D., Nascimento, D.L.D.M., Araújo, F.M., Abreu, R.H., Papadopoulos, N.A., Demay, M.B. and Tortorella, G. (2023), "Interoperability framework for subsea sensors data", *EC3 Conference 2023*, European Council on Computing in Construction, Vol. 4.

Chacko, E., Suresh, M. and Sreenivasan, A. (2023), "Factors influencing agility on start-ups: a TISM approach", *International Journal of Agile Systems and Management*, Vol. 16 No. 1, pp. 25-43, doi: 10.1504/IJASM.2023.130480.

Citybabu, G. and Yamini, S. (2023a), "Lean six sigma 4.0–a framework and review for lean six sigma practices in the digital era", *Benchmarking: An International Journal*.

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, doi: 10.1016/j.ijpe.2012.05.035.

de Mattos Nascimento, D.L., de Oliveira-Dias, D., Moyano-Fuentes, J., Maqueira Marín, J.M. and Garza-Reyes, J.A. (2024), "Interrelationships between circular economy and industry 4.0: a research agenda for sustainable supply chains", *Business Strategy and the Environment*, Vol. 33 No. 2, pp. 575-596.

De Mattos Nascimento, D.L., Sotelino, E.D., Caiado, R.G.G., Ivson, P. and Faria, P.S. (2017), "Sinergia entre princípios do lean thinking e funcionalidades de BIM na interdisciplinaridade de gestão em plantas industriais", *Journal Of Lean Systems, Rio De Janeiro*, Vol. 2 No. 4, pp. 80-105.

Divisão de Saúde e Segurança no Trabalho (SESI) (2007), *Referência Técnica: exames Médicos Previstos No Programa De Controle Médico De Saúde Ocupacional/SESI-SP e ABRESST*, SESI, São Paulo.

Dombrowski, U. and MIelke, T. (2014), "Lean leadership–15 rules for a sustainable lean implementation", *Procedia CIRP*, Vol. 17, pp. 565-570, doi: 10.1016/j.procir.2014.01.146.

Eastman, C.M., Jeong, Y.S., Sacks, R. and Kaner, I. (2010), "Exchange model and exchange object concepts for implementation of national BIM standards", *Journal of Computing in Civil Engineering*, Vol. 24 No. 1, pp. 25-34.

Endler, K.D., Bourscheidt, L.E., Scarpin, C.T., Arns Steiner, M.T. and da Rosa Garbuio, P.A. (2016), "Lean seis sigma: uma contribuição bibliométrica dos últimos 15 anos", *Revista Produção Online*, Vol. 16 No. 2, pp. 575-605, doi: 10.14488/1676-1901.v16i2.2023.

Fontoura, L., de Mattos Nascimento, D.L., Neto, J.V., Garcia-Buendia, N., Garza-Reyes, J.A., Lima, G.B.A. and Meiriño, M.J. (2023), "Real-time energy flow mapping: a VSM-based proposal for energy efficiency", *Journal of Cleaner Production*, Vol. 419, p. 137871.

Franchetti, M.J. (2015), *Lean Six Sigma for Engineers and Managers: With Applied Case Studies*, CRC Press, available at: https://books.google.es/books?hl=en&lr=&id=lXsZBwAAQBAJ&oi=fnd&pg=PP1&dq=Franchetti,+M.J.+(2015),+Lean+Six+Sigma+for+Engineers+and+Managers&ots=kx0dBc6OZW&sig=GHwOxiOEuhWP4iao8DK3HaWlGKZg#v=onepage&q=Franchetti%2C%20M.J.%20(2015)%2C%20Lean%20Six%20Sigma%20for%20Engineers%20and%20Managers&f=false

George, M.L. (2003), *Lean Six Sigma for Service: How to Use Lean Speed and Six Sigma Quality to Improve Services and Transactions*, McGraw-Hill, New York, NY.

Gueiros, S. (2006), "Estudo Para uma classificação e navegação nas normas regulamentadoras em segurança e medicina do trabalho – NRs", Encontro Nacional de Auditores Fiscais do Ministério do Trabalho, Recife.

Jackson, S. and Philip, G. (2010), "A techno-cultural emergence perspective on the management of techno-change", *International Journal of Information Management*, Vol. 30 No. 5, pp. 445-456.

Kumar, S., Luthra, S., Govindan, K., Kumar, N. and Haleem, A. (2016), "Barriers in green lean six sigma product development process: an ISM approach", *Production Planning and Control*, Vol. 27 Nos 7/8, pp. 604-620, doi: 10.1080/09537287.2016.1165307.

Leite, D.G. and Montesco, R.A.E. (2016), "Aplicação do lean seis sigma na melhoria de processo de uma distribuidora de GLP em aracaju/SE", *Encontro Nacional De Engenharia De Produção*, Vol. 36, pp. 1-18.

León, H.C.M. and Calvo-Amodio, J. (2017), "Towards lean for sustainability: understanding the interrelationships between lean and sustainability from a systems thinking perspective", *Journal of Cleaner Production*, Vol. 142, pp. 4384-4402, doi: 10.1016/j.jclepro.2016.11.132.

Maleyeff, J., Arnheiter, E.A. and Venkateswaran, V. (2012), "The continuing evolution of lean six sigma", *The TQM Journal*, Vol. 24 No. 6, pp. 542-555, doi: 10.1108/17542731211270106.

Marshall, I., Jr, Rocha, A.V., Mota, E.B. and Quintella, O.M. (2012), *Gestão Da Qualidade e Processo*, 1st ed. FGV, Rio de Janeiro.

Ministério do Trabalho (1978), *Portaria n° 3.214*, Diário Oficial da União, Brasília.

Ministério do Trabalho e Emprego (2013), "NR 7 – programa de controle médico de saúde ocupacional", Ministério do Trabalho e Emprego do Brasil.

Ministério do Trabalho e Emprego (2014), "NR 15 – atividades e operações insalubres", Ministério do Trabalho e Emprego do Brasil.

Ministério do Trabalho e Emprego (2016), "NR 9 – programa de prevenção de riscos ambientais", Ministério do Trabalho e Emprego do Brasil.

Miranda, C.R. and Dias, C.R. (2004), "PPRA/PCMSO: auditoria, inspeção do trabalho e controle social", *Cadernos De Saúde Pública*, Vol. 20 No. 1, pp. 224-232, doi: 10.1590/S0102-311X2004000100039.

Mor, R.S., Bhardwaj, A., Singh, S. and Sachdeva, A. (2019), "Productivity gains through standardization-of-work in a manufacturing company", *Journal of Manufacturing Technology Management*, Vol. 30 No. 6, pp. 899-919, doi: 10.1108/JMTM-07-2017-0151.

Nascimento, D.L.D.M., Goncalvez Quelhas, O.L., Gusmão Caiado, R.G., Tortorella, G.L., Garza-Reyes, J.A. and Rocha-Lona, L. (2020), "A lean six sigma framework for continuous and incremental improvement in the oil and gas sector", *International Journal of Lean Six Sigma*, Vol. 11 No. 3, pp. 577-595.

Pinheiro, S., Wimmer, R., O'Donnell, J., Muhic, S., Bazjanac, V., Maile, T., Frisch, J. and van Treeck, C. (2018), "MVD based information exchange between BIM and building energy performance simulation", *Automation in Construction*, Vol. 90, pp. 91-103.

Pongboonchai-Empl, T., Antony, J., Garza-Reyes, J.A., Komkowski, T. and Tortorella, G.L. (2023), "Integration of industry 4.0 technologies into lean six sigma DMAIC: a systematic review", *Production Planning and Control*, pp. 1-26, doi: 10.1080/09537287.2023.2188496.

Popa, A., Ramos, R., Cover, A. and Popa, C. (2005), "Integration of artificial intelligence and lean sigma for large-field production optimization: application to kern river field", *SPE Annual Technical Conference and Exhibition*, SPE, pp. SPE-97247, doi: 10.2118/97247-MS.

Psarommatis, F., Sousa, J., Mendonça, J.P. and Kiritsis, D. (2022), "Zero-defect manufacturing the approach for higher manufacturing sustainability in the era of industry 4.0: a position paper", *International Journal of Production Research*, Vol. 60 No. 1, pp. 73-91, doi: 10.1080/00207543.2021.1987551.

Ribeiro, F.P.L. (2014), "Auditoria de programa de controle médico e saúde ocupacional: proposta de protocolo específico a partir das exigências da norma regulamentadora n° 7", *Sumário*, Vol. 12 No. 2.

Saliba, T.M. and Corrêa, M.A.C. (2022), *Insalubridade e Periculosidade: aspectos Técnicos e Práticos*, 18th ed., LTr Editora. available at: https://books.google.es/books?hl=en&lr=&id=MXZ8EAAAQBAJ&oi=fnd&pg=PA4&dq=Saliba,+T.M.+and+Corr%C3%AAa,+M.A.C.+(2022),+Insalubridade+e+Periculosidade:+aspectos+T%C3%A9cnicos+e+Pr%C3%A1ticos&ots=ZXJqo3Uzho&sig=zPPYqI5zgyg5IuHLeO56K7pstHo#v=onepage&q&f=false

Santos, A.C.D.S.G.D., Reis, A.D.C., Souza, C.G.D., Santos, I.L.D. and Ferreira, L.A.F. (2020), "The first evidence about conceptual vs analytical lean healthcare research studies", *Journal of Health Organization and Management*, Vol. 34 No. 7, pp. 789-806, doi: 10.1108/JHOM-01-2020-0021.

Servin, C.A.L., Santos, L.C. and Gohr, C.F. (2012), "Aplicação da metodologia DMAIC Para a redução de perdas por paradas não programadas em uma indústria moageira de trigo", Anais Do Encontro Nacional De Engenharia De Produção, Bento Gonçalves-RS, available at: www.google.es/books/edition/Gest%C3%A3o_Estrat%C3%A9gica_de_Opera%C3%A7%C3%B5es/ymr6EAAAQBAJ?

hl=en&gbpv=1&dq=Aplica%C3%A7%C3%A3o+da+metodologia+DMAIC+Para+a+redu%C3%A7%C3%A3o+de+perdas+por+paradas+n%C3%A3o+programadas+em+uma+ind%C3%BAstria+moageira+de+trigo&pg=PT121&printsec=frontcover

Silva, E.S.N. and Santos, T.F.V. (2014), "Análise dos padrões técnicos de programas de controle médico de saúde ocupacional e atestados de saúde ocupacional por meio de auditoria interna", *Revista Brasileira De Medicina Do Trabalho*, Vol. 12 No. 2, pp. 50-56.

Sokovic, M., Pavletic, D. and Pipan, K.K. (2010), "Quality improvement methodologies – PDCA cycle, RADAR matrix, DMAIC and DFSS", *Journal of Achievements in Materials and Manufacturing Engineering*, Vol. 43 No. 1, pp. 476-483.

Sordan, J.E., Marinho, C.A., Oprime, P.C., Pimenta, M.L. and Andersson, R. (2022), "Characterization of lean six sigma projects in healthcare settings: empirical research", *Benchmarking: An International Journal*, Vol. 30 No. 10, pp. 4058-4075, doi: 10.1108/BIJ-03-2022-0183.

Tortorella, G., Nascimento, D., Caiado, R., Arrieta Posada, J.G. and Sawhney, R. (2020), "How do different generations contribute to the development of a learning organization in companies undergoing a lean production implementation?", *The Learning Organization*, Vol. 27 No. 2, pp. 101-115.

Voehl, F., Harrington, H.J., Mignosa, C. and Charron, R. (2010), *The Lean Six Sigma Black Belt Handbook – Tools and Methods for Process Acceleration*, Taylor and Francis Group, available at: https://books.google.es/books?hl=en&lr=&id=EHcVk4K6HcEC&oi=fnd&pg=PP1&dq=The+Lean+Six+Sigma+Black+Belt+Handbook+-+Tools+and+Methods+for+Process+Acceleration&ots=T5zAF2_m0B&sig=UcaSRFCAEBbYjlVLYJWjrYp4_rk#v=onepage&q=The%20Lean%20Six%20Sigma%20Black%20Belt%20Handbook%20-%20Tools%20and%20Methods%20for%20Process%20Acceleration&f=false

Werkema, M.C.C. (2013), *Métodos PDCA e DMAIC e Suas Ferramentas Analíticas*, 1st ed. Elsevier, Belo Horizonte.

Further reading

Citybabu, G. and Yamini, S. (2023b), "Lean six sigma and industry 4.0–a bibliometric analysis and conceptual framework development for future research agenda", *International Journal of Productivity and Performance Management*.

Singh, P.K., Maheswaran, R., Virmani, N., Raut, R.D. and Muduli, K. (2023), "Prioritizing the solutions to overcome lean six sigma 4.0 challenges in SMEs: a contemporary research framework to enhance business operations", *Sustainability*, Vol. 15 No. 4, p. 3371.

Skalli, D., Charkaoui, A., Cherrafi, A., Shokri, A., Garza-Reyes, J.A. and Antony, J. (2023), "Analysis of factors influencing circular-lean-six sigma 4.0 implementation considering sustainability implications: an exploratory study", *International Journal of Production Research*, pp. 1-28.

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Appendix 1

Table A1. Exchange information requirements (EIRs) for defining the occupational exams process

Task	Name	Supplying actor	Required information	Data type	Supporting standards	Source
Check occupational risk	Info 1	QHSE	Homogeneous Exposure Group	Numbers and text	NR 9	Manual
			Occupational Risk	Text	NR 9	
			Function (job title)	Text	NR 9	
			Exposure assessment methodology	Numbers and text	NR 15 and NR 9	
Review occupational risk recognition	Info 3	QHSE	PPRA reapproval	Numbers and text	NR 15 and NR 9	Manual
			Homogeneous Group of Exposure	Numbers and text		
			Occupational Risk	Text		
			Function (job tittle)	Text		
			Exposure assessment methodology	Numbers and text		
Define exams	Info 2	Health service supplier	PPRA approval	Text	NR 9	Manual
			Homogeneous Group of Exposure	Numbers and text	NR 9	
			Occupational Risk	Text	NR 9	
			Function (job tittle)	Text	NR 9	
			Risk concentration	Number	NR 15	
				Text		
				Boolean: (Concentration > LT; NA < Concentration < LT; Concentration < NA)		
			Parameters for monitoring occupational exposure to occupational risks	Text Numbers	NR 7	Manual
			Parameters for biological control of occupational exposure to chemical risks	Text Numbers	NR 7	Manual

(continued)

Table A1.

Task	Name	Supplying actor	Required information	Data type	Supporting standards	Source
Control exams	Info 4	HR	PCMSO: relation between job functions, occupational risks, exams and frequency	Text Numbers	NR 7	Software
			Employee name	Text	NR 7	Software
			Exam expiration date	Numbers	NR 7	Software
	Info 7	Employee	Occupational health attested	Boolean (Yes/No) Text Numbers	NR 7	Software
Submit exam request	Info 5	HR	E-mail employee	Text Numbers	NR 7	Manual
			Medical consultation form	Text Numbers	NR 7	Software
Accomplish the exams	Info 6	Employee	Medical consultation form	Text Numbers	NR 7	Manual
			Employee ID	Text Numbers	NR 7	Manual

Source: Authors' own creation

Appendix 2

Table A2.
Cause-and-effect correlation matrix

	Effects	Excess of exams for certain functions with error GHE	Inability to quantify the concentration of chemical products	Inability to quantify the concentration of chemical products and vibration	Inability to analyze the concentration of chemical products and vibration with LT and LA	Increased number of exams related to chemicals products	Increased number of exams related to vibration	Increased number of exams related to metallic dust, BTX and metallic fumes	PCMSO does not correspond to the occupational risks of the company	Results	No. of causes related to effects
Causes	*Points (5 until 10)*	*5*	*10*	*10*	*10*	*10*	*8*	*7*	*6*	*Total*	*Total*
	Inadequate environmental recognition	3	0	0	0	5	5	0	0	105	3
	Chemical risks assessment procedure does not match with the activities performed in the company	5	5	5	0	5	0	0	0	175	4
	Monitoring of occupational risks was not performed	*3*	*5*	*5*	*5*	*5*	*5*	*0*	*5*	*285*	*7*
	The metal fumes, metal dust and BTX concentration were not compared with its action level (LA) and tolerance limit (TL)	0	0	0	0	0	0	5	5	65	3
	Inadequate compliance with legal requirement NR 15	0	5	5	5	3	3	0	5	234	6
	Inadequate compliance with legal requirement NR 9	5	0	0	5	3	3	5	5	194	6
	Absence of approval of the PCMSO by the QHSE unit	0	0	0	0	0	0	3	5	51	2

(*continued*)

Effects	Excess of exams for certain functions with error GHE	Inability to quantify the concentration of chemical products	Inability to quantify the concentration of chemical products and vibration	Inability to analyze the concentration of chemical products and vibration with LT and LA	Increased number of exams related to chemicals products	Increased number of exams related to vibration	Increased number of exams related to metallic dust, BTX and metallic fumes	PCMSO does not correspond to the occupational risks of the company	Results	No. of causes related to effects
Inadequate compliance with legal requirement NR 7	0	0	0	0	0	0	0	5	30	1
Missing correlation	0									
Weak correlation	1									
Moderate correlation	3									
Strong correlation	5									

Source: Authors' own creation

Table A2.