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Original Article

Business Process Model Re-Design with A Data-Based Green Lean Management Approach with OEEM: A Case of Plastic Product Manufacturing Firm

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Abstract *- This study addresses the growing need for sustainable practices in the manufacturing industry, driven by increased awareness of environmental impacts and regulatory pressure to reduce emissions. It explores the application of the Overall Equipment Effectiveness Method (OEEM) within the framework of Green Lean Management, emphasizing a data-driven approach to sustainable business process optimization. Despite the rising interest in OEEM, research on its implementation remains scarce, particularly regarding the barriers hindering its adoption. This article identifies and categorizes these barriers through a literature review and principal component analysis using a case study from the plastic manufacturing sector. The findings demonstrate how strategic OEEM implementation, supported by Lean Management tools (5S, TPM, SMED), can enhance machine efficiency, as evidenced by a 7.72% increase in availability and a 7.51% improvement in performance. The reduction in setup times from 248 to 117.5 minutes further underscores the effectiveness of this approach. This research provides critical insights for policymakers and industry leaders, promoting the adoption of OEEM to align economic development with environmental sustainability.*

Keywords *- Business data analytics, Green business process model, Lean management, Overall Equipment Effectiveness Method (OEEM), Sustainability.*

1. Introduction

The surge in global plastic production over the past few decades has marked a significant shift in materials consumption, exceeding the output of any other material in the last 150 years. [1]. Although there was a slight decline in 2020 due to the pandemic, plastic production is projected to reach 619 million tons by 2030 [2]. In 2023, this growth is estimated to exceed the 413.8 million tons. Predominantly led by Asian countries, particularly China, which accounts for 33.3 percent of the global total [3], the plastic industry faces critical environmental challenges, with 57 percent of the waste finding its way into natural environments like rivers and landfills, posing severe threats to the ecosystem[4]. Environmental concerns have escalated, prompting organizations like the World Economic Forum to advocate for a drastic reduction in plastic production to mitigate environmental emissions [2]. Balancing the environmental impact with the economic significance of the plastic industry, which is a significant job creator, poses a dilemma for policymakers and industry stakeholders [3]. The injection molding process, utilized by over 90 percent of plastic industries globally, stands at the core of plastic manufacturing [5]. For companies operating in this sector, optimizing the injection molding machine's performance becomes paramount for overall operational efficiency [6]. However, many companies encounter challenges, such as frequent machine stoppages and extended setup times, which contribute significantly to inefficiencies. The conference paper "Operations management model based on 5S, TPM, and SMED to increase the effectiveness of equipment in a Plastic Company" is a prior work to this research, providing a complete analysis of the problem: the low effectiveness of the injection molding machine. It also outlines an innovative proposal and general model supported by a literature review on the topic, focusing on applying tools such as 5S, TPM, and SMED as solutions to the identified problem. This research focuses on a specific company within the plastic manufacturing sector grappling with inefficiencies in its molding process. The primary issues revolve around frequent stoppages due to prolonged setup times (57.6 percent) and injection molding machine failures (41.1 percent). The Overall Equipment Effectiveness (OEE) is the key performance indicator, revealing a suboptimal machine effectiveness of 53.1 percent. Critical parameters such as availability (69.96 percent) and performance (79.18 percent) stand out as major contributors to this sub-optimal performance [7]. In contrast to the plastics sector benchmark, the company faces a significant research gap of 15.2 percent, emphasizing the need for improvement by applying Green Lean Manufacturing tools. Consequently, the main problem identified is the low effectiveness of the injection molding machine (53.1 percent). Almashaqbeh and Munive Hernandez [8] analyzed a plastic production company in Jordan over three months, identifying key performance losses, including speed losses (58.1 percent) and interruptions (12.7 percent). By applying the DMAIC model, maintenance procedures, and operational strategies like installing a robot to reduce downtime, the company improved its OEE from 63.8 percent to 88.9 percent. Makwana et al. [9] adopted Lean Manufacturing, integrating the PDCA cycle and Kaizen, to enhance productivity and quality in a plastic conversion machinery assembly company. Their efforts led to a 41.66 percent increase in productivity and reduced assembly time from 25.16 to 10.48 minutes.

The urgency to address these efficiency challenges is underscored by the immediate impact on the company's viability, environmental responsibilities, and the overarching sustainability of the plastic manufacturing industry. Inaction not only jeopardizes the company's competitiveness but also perpetuates environmental harm. As such, this research is a theoretical exploration and a crucial step towards rectifying an urgent problem with far-reaching consequences. This research makes a scholarly contribution by addressing efficiency issues in the injection molding process of the plastic manufacturing sector through the practical application of Lean Manufacturing principles, specifically 5S, TPM, and SMED. Grounded in existing literature, the study introduces a novel solution to enhance Overall Equipment Effectiveness (OEE) and operational efficiency. The comprehensive literature review on Lean Manufacturing establishes a robust foundation for understanding these principles and practices. It contributes to the academic discourse on integrating Lean Manufacturing into plastic manufacturing. The methodology section outlines a systematic approach, incorporating a defined model and specialized tools to address identified issues. The research design, including using the Arena simulator, provides a methodological framework that can guide future research in similar contexts.

Furthermore, this research extends its contributions to economic and social dimensions. Focusing on the injection molding process, the study directly tackles operational inefficiencies. The proposed Lean Manufacturing tools aim to contribute to economic sustainability by increasing production efficiency, reducing machine failures, and minimizing resource waste. Benchmarking the company's performance against industry standards highlights a significant performance gap, encouraging performance evaluations for specific companies and providing valuable insights for the broader plastic manufacturing industry. The research also holds policy implications. Addressing the environmental impacts of plastic production and balancing them with the industry's crucial role as a job creator presents a policy dilemma. Organizations like the World Economic Forum, advocating for a reduction in plastic production, can find guidance in navigating this delicate balance. Moreover, emphasizing the immediate need to address efficiency challenges, the study underscores that inaction jeopardizes a company's competitiveness and perpetuates environmental harm. This research goes beyond theoretical exploration, representing a crucial step toward rectifying an urgent problem with far-reaching consequences.

The structure of this study is organized to provide a complete understanding of the proposed solution. Section 2 reviews the existing literature related to the selected tools across various industries and successful case studies. Section 3 delves into a theoretical background of lean production management and sustainable operation management. Section 4 outlines the research methodology, emphasizing the general model and details of selected tools, including 5S, TPM, and SMED, as well as the scenario. Section 5 presents the results through the Arena Software, with an in-depth analysis of scenarios and results. Section 5 is the discussion that compares the obtained results with success cases from other authors, offering a broader perspective. The paper concludes in Section 6 with a summary of research findings and their implications for the plastic manufacturing industry.

2. Literature Review

Lean Manufacturing is a project management methodology aimed at delivering a valuable product or service to customers by improving productivity at work through eliminating waste [84]. This methodology originated in the Toyota company in the 1950s when there was a need to produce small cars cheaply. However, the concept did not gain worldwide recognition until the 1990s after the publication of "The Machine That Changed the World" by Womack and Jones. On the other hand, human capital in Lean tools is the key to success as it involves collaboration from workers to top executives in the company [6]. Additionally, the corporate culture emphasizes innovation, where employees can identify and solve problems [11]. Among the principles used when implementing the lean manufacturing philosophy in a company are doing it right the first time or zero defects, where problems are solved at their source. There are also activities without added value to the customer experience [83]. Another important point is pulling processes, which aim to avoid excess inventory and ensure flexibility in producing different types of products with accuracy in quantities. Long-term relationships with suppliers and the end customer are also emphasized, seeking to provide a solution to their needs [14]. In fact, the principles of Lean Manufacturing cover all aspects of both production and service organizations and have a significant impact on their efficiency and effectiveness [15].

According to some studies, companies can achieve a cost reduction of up to 50% after implementing this methodology [29]. Among the benefits of this methodology, known as Lean Production, is cost reduction in company processes to avoid overproduction, the elimination of waste to optimize resources, and finally, the improvement of quality and efficiency to keep the company competitive in the market and utilize resources more effectively [29]. Additionally, among the most important tools for the manufacturing industry are total productive maintenance (5S), reduction of machine setup time (SMED), the five principles for workplace organization and overall process standardization [30].

2.1. 5S Methodology

The 5S method originated in Japan and is based on five principles, each starting with the letter "S." Each principle represents a stage in the process and is complemented by continuous improvement, known as Kaizen [69]. It also helps anticipate unfavorable scenarios to manage crises and promotes cleanliness in the workplace. The expected results of this method can be seen in the short term by increasing process efficiency. This tool is considered a productive system for companies with multiple processes [70]. Various authors point to the success of this methodology in worker training, as its objective is to standardize work, facilitate the visualization of abnormalities in the process, and facilitate their respective elimination [71].

That's why, over the years, this tool has successfully addressed many company problems. One example is the productivity improvement in a plastic manufacturing company that faced issues with long material search times, causing delays in the assembly area. To solve this problem, the workers' total participation was required over seven months. The results showed a reduced material search time of 5 hours per month and increased productivity from 75% to 100% [70]. On the other hand, another company in the same industry had waste issues that affected the operational time of the blow molding and printing process. To address this, reductions were achieved, decreasing waste from 12.12% to 8% in the blow molding process and from 34.78% to 18% in the printing process, respectively [71]. Another relevant case study occurred in a small-scale manufacturing industry with high waste rates. The productivity before implementation was at 60% due to the issues at hand. In order to address this, the workers were motivated by improving the work environment. The results showed a 55% increase in productivity in the first year after implementation [72].

2.2. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is known as a Japanese-origin continuous improvement system that focuses on significantly increasing production in a company while enhancing employee motivation [5, 30]. This philosophy aims to involve human capital at all levels for long-term proper functioning [73]. In various studies, Overall Equipment Effectiveness (OEE) is defined as the primary indicator for measuring performance after implementing this lean tool [74]. Furthermore, it is subdivided into three indicators: availability, which represents the equipment's operating time; performance, which compares actual production to the planned production; and quality, which measures operating time against the expected outcome [7]. A particular case study for this research occurred in a plastic injection company, where the problem arose due to a high number of machine breakdowns. Initially, the process had an average OEE of 50%. The authors focused on this specific process as it was the most significant in the industry. A planned maintenance proposal was implemented to address this issue for the two malfunctioning machines. The results showed an efficiency increase of 11.43% and 9.2% for both equipment, respectively, after implementing TPM [7].

In another investigation conducted in Malaysia, an issue of excessive quantity of reprocessed products, bottlenecks, and delays in delivery times was found. To address this, the authors implemented the philosophy of autonomous maintenance with continuous improvement Kaizen. Three key indices were used to measure the improvement: variability, current productivity, and plant performance. The results were as expected by the researchers, as the cycle time was reduced by 33% and processing time by 6.3% [74]. Furthermore, it was found relevant to use a reference from a case study where the philosophy of total productive maintenance with a continuous improvement approach was used for a company manufacturing PVC pipe product. The problem revolved around customer dissatisfaction due to products not meeting the given specifications. The OEE indicator measured the initial situation, which stood at 55.45%. However, the authors relied on a global study for the same sector, which had a gap of 60%. After implementing this methodology, the indicator was improved to 68%. In other words, it surpassed the gap, leading to a decrease in the number of rejections and an increase in customer satisfaction [75].

2.3. Single-Minute Exchange of Die (SMED)

SMED is considered a working technique to reduce setup times in a production line. In general, the goal is to decrease it to a single digit, less than 10 minutes [76]. That's why it is considered one of the lean manufacturing tools, as it helps companies achieve significant cost savings [30]. This method originated from the need to reduce batch size in a Japanese company and was implemented by Shigeo Shingo [77].

A series of concepts were defined to implement this methodology, such as the changeover time from manufacturing one product to the next when the equipment is idle [78]. Another concept is operation preparation, which is considered a non-value-added activity [79]. These preparations are divided into internal and external setups, and many researchers recommend transforming internal setups into external setups while the machine is still running.

Some authors have applied this method to generate expected results for companies. One of them was the case of a waste problem that led to overproduction in the screw cap process. High setup times were detected, accounting for 27.7% of the total time. Two phases were proposed for implementing the technique to address this issue. The results show a reduction of 15% in cutting times, 88% in printing, and 68% in knurling. Additionally, 180m2 of space was saved within the plant [77]. On the other hand, in Parwani's study, the issue of unproductive times due to the change of plastic parts in a rotary thermoforming machine was identified. Currently, the company loses 165 minutes per day across three shifts. To address this issue, it is proposed to reduce setup times by implementing five phases: measurement, unnecessary delays, transformation into external activities, elimination of non-value-added activities, and standardization. As a result, the setup time is reduced to 9 minutes per shift, and programming costs are decreased by 6% [80].

3. Theoretical Background

3.1. Lean Production Management

In this section, we will thoroughly examine the evolution, fundamental principles, and applications of Lean Manufacturing. In the effort to deliver value to customers, Lean Manufacturing emerged as a project management methodology that originated at Toyota in the 1950s and gained worldwide recognition in the late 1990s with the publication of The Machine That Changed the World [10]. Central to its philosophy is eliminating waste in work processes and emphasizing the significance of human capital in its successful implementation. Collaboration across all organizational levels, from frontline workers to top-level executives, is deemed crucial, as critically evaluated [6]. This collaborative approach is aligned with the principles of continuous improvement inherent in Lean Manufacturing, fostering a corporate culture that prioritizes innovation and encourages employees to identify and resolve challenges [11].

Therefore, integrating processes generates huge opportunities to improve costs, quality, and response times in different organizations [12]. Therefore, Lean Manufacturing (LM) and its associated methodologies have been widely studied and applied across various industries to enhance operational efficiency, reduce waste, and improve overall performance. This literature review synthesizes recent research on lean methodologies' implementation, challenges, and outcomes in diverse contexts, including manufacturing, services, and software development. Sartal et al. have explored the cultural dimensions of lean transformations in Western companies, contrasting lean-toolbox and lean-culture perspectives [13]. They have argued that cultural change mediates the relationship between lean tool deployment and enhanced performance, providing a framework for integrating Western and Japanese approaches to lean implementation. Their empirical study on 1692 North American manufacturing firms underscores the importance of aligning cultural transformations with the deployment of lean tools to achieve superior plant performance. Therefore, implementing Lean Manufacturing in companies is guided by a set of principles encompassing various critical elements. The principle of doing it right the first time or achieving zero defects underscores the methodology's commitment to addressing problems at their source and minimizing errors [5]. The main objective of Lean is a fast, flexible, and high-quality response to the customer, emphasizing its measurement through efficiency and effectiveness in addressing problems. Moreover, the philosophy involves meticulously examining processes to identify activities that do not add value to the customer experience. The 'pulling processes' principle avoids excess inventory, ensuring flexibility in producing different products with precise quantities.

Emphasis is placed on building long-term relationships with suppliers and end customers, proactively addressing their needs [14]. These principles significantly impact all facets of production and service organizations, substantially enhancing their efficiency and effectiveness [15]. Prajogo, Mena, and Nair examine the fit between supply chain strategies and practices using a contingency model [16]. They find that flexibility-oriented strategies align better with dynamic business environments than low-cost strategies. Their research highlights the importance of supplier assessment, long-term relationships, and logistics integration in supporting flexibility strategies. This study emphasizes the need for supply chain strategies to adapt to environmental contingencies to optimize performance.

At the core of the Lean Manufacturing philosophy is the assertion that pulling raw materials, semi-finished goods, and materials is a mechanism primarily aimed at limiting continuous work and that lean practices essentially seek to minimize the cost of buffering variability [17]. A lean organization's fundamental requirement is to be an enterprise that can meet target customers' needs by connecting and synchronizing all elements of the value distribution system, a widely accepted principle [18]. In this context, the philosophy of lean production requires balance. This balance should be embraced by the entire organization as a philosophy, and practices across all business functions should be implemented at the centre of this philosophy to meet customer needs just in time. However, Hopp and Spearman have argued that the lean production philosophy is poorly understood because success in lean initiatives is not achievable merely by imitating good examples [17]. Especially during crises, lean practices carried out by neglecting their own characteristics and sectoral needs may encounter various problems in an environment of uncertainty. Notably, a crisis in logistics and supply on a global scale can pose threats to organizations that have embraced lean production. A case study conducted by Brown et al. has revealed three significant threats that lean initiatives may potentially face during a global logistics and supply crisis: the locked operation model, reverting to pre-lean practices, and lean islands [18]. The locked operation model emphasizes the inability to alter the value distribution system in response to market and economic disruptions. On the other hand, re-entering activities based on waste inventory storage, accumulated tasks, and complexity in business processes are identified as a problem regressing from the lean philosophy. Another challenge faced by lean initiatives is the lean islands problem, where lean practices remain within the organizational boundaries [18]. Azevedo et al. have proposed a theoretical framework to analyze the effect of green and lean upstream supply chain practices on business sustainability [19].

Their case study in the automotive industry reveals that integrating green and lean practices enhances economic, environmental, and social performance measures. This study highlights the synergistic benefits of combining green and lean strategies in supply chain management. Colombari and Neirotti have investigated the function of frontline employees' knowledge in operational data-driven decision-making (DDM) within lean production environments [20]. Their multilevel study shows that high-involvement lean practices and skilled frontline managers enhance the adoption of DDM. Integrating organizational and individual dimensions into the decision-making cycle underscores the importance of leveraging frontline knowledge for effective lean implementation. Galankashi et al. have proposed a multiobjective mathematical model integrating Aggregate Production Planning (APP) with lean manufacturing principles [21].

Their model optimizes cost, lead time, waste minimization, and product quality across multiple case studies. Integrating APP and lean methodologies offers a comprehensive approach to production planning, addressing critical lean concerns such as overproduction and sourcing. Krishnan, Mathiyazhagan, and Sreedharan have developed a hybrid Lean Six Sigma (LSS) framework incorporating the SDMMAICS model and DEMATEL for decision-making [22]. Applied in a reamer manufacturing context, their approach improves process efficiency and cycle time, demonstrating the practical benefits of combining LSS with decision-making techniques for continuous improvement. Finally, Ganjavi and Fazlollahtabar developed a sustainable production value measurement model that integrates lean and six sigma within the context of Industry 4.0 [23]. Their approach emphasizes the importance of processing large data volumes to enhance quality management. By combining lean six sigma with advanced production systems, their model provides a robust framework for achieving sustainability in manufacturing. However, the philosophy of lean initiatives can be adopted effectively for ventures outside the manufacturing sector. Demirkesen and Bayhan have established Key Success Factors (CSFs) for lean implementation in the construction industry [24]. They find that management commitment is paramount, while governmental support is less influential. Their factor analysis groups CSFs into motivational, project, strategic, company, technical, and workforce factors, providing a comprehensive roadmap for successful lean adoption in construction projects. Monserrat et al. have applied lean principles to improve the management of a Software Project Management module in higher education [25]. They used value stream mapping to identify and minimize waste, enhancing the value provided to students. Their study illustrates how lean techniques can be adapted for educational contexts to streamline processes and improve learner outcomes. Sum et al. analyzes implementing lean principles in a Shared Service Center (SSC) context [26].

They develop specific metrics to evaluate stability and capacity in lean implementations, demonstrating that even mature SSC processes have significant improvement opportunities. Their findings suggest that lean methodologies can elevate the level of excellence in SSCs by focusing on stability and capacity indicators. Middleton and Joyce have investigated the application of lean principles to software project management at BBC Worldwide [27]. Their case study demonstrates significant improvements in lead time, delivery consistency, and defect reduction through lean methods such as visual management and team-based problem-solving. This study highlights the effectiveness of lean approaches in the software development domain, differentiating between agile and lean methodologies.

Moreover, Betcheva et al. have provided an excellent example of the successful adoption of the lean initiative philosophy in the healthcare sector [28]. This study demonstrates how the complex and inefficient healthcare ecosystem, much like supply chain practices, can be revitalized through structural improvements and principles of timely response to customer needs. As a result of this study, the costs of a healthcare organization have decreased, the completion cycle of service processes has shortened, and the perception of quality has increased. Thus, it can be argued that the lean philosophy contributes to developing a beneficial business model for service enterprises. Moreover, there is no sectoral limitation to adopting the lean philosophy; this study makes a crucial contribution to the literature by addressing the issues that need to be considered in adopting the lean philosophy for the well-being of individuals and society. Research indicates that companies can achieve substantial cost reductions, up to 50 percent, by adopting lean manufacturing methodologies [29]. Termed as Lean Production, this methodology yields a spectrum of benefits, including the reduction of costs associated with company processes to prevent overproduction, the elimination of waste to optimize resources, and the enhancement of quality and efficiency to maintain competitiveness in the market and utilize resources more effectively [29]. In the manufacturing industry, the adoption of Lean Manufacturing is supported by key methods such as total productive maintenance (5S), Reduction of

Machine Setup Time (SMED), the five principles for workplace organization, and overall process standardization [30]. These tools play a pivotal role in realizing the objectives of Lean Manufacturing, contributing significantly to the overarching goal of organizational excellence. Additionally, it is emphasized that the focus of the lean philosophy should not be solely on generating financial income or reducing costs. Atasu et al. have suggested that well-being is more important than wealth from a sustainability perspective for individuals and societies [31]. In this context, the necessity of adopting the lean philosophy for the well-being of individuals and society is highlighted. However, the critical point in the study is that for the success of the lean philosophy, the relationship between operations and well-being should be approached from a different perspective. Within the scope of the study, the operations of a healthcare institution are divided into seven main areas: predictability and probability, process and prevention, performance and payment, speed and productivity, and pollution and protection. Considering these areas, dissatisfaction related to individual service quality was identified separately and improved. This approach provides a comprehensive evaluation of the use of the lean philosophy for service enterprises, especially for the healthcare sector, and significantly contributes to the literature. We present a detailed comparison of Lean Production, Green Technology, and Six Sigma across various fundamental features in Table 1 based on the insight of Ruben et al. and Garza-Reyes [32, 33]. This comparison elucidates each methodology's focus, impact on competitiveness and profitability, approaches to waste reduction and customer orientation.

Table 1. Comparison between lean production, green technology, and six sigma

Variables	Lean Production View	Green Technology View	Six Sigma View
Focus	Improve industry performance by minimizing waste	Increase energy utilization efficiency to improve ecological efficiency	Improve performance through reduction in defective parts
Competitiveness	Increase organizational profitability by eliminating various non-value-added activities.	A solid focus on competitiveness through the reduction of environmental effects.	More competition by offering high-quality products and less need for rework.
Waste	Primarily focus on waste reduction to lower costs	Focus on environmental waste reduction	Defects reduction leads to lesser rework
Customers	Reducing costs and focusing on customers by getting rid of unnecessary activities.	Strive to earn customer satisfaction by creating eco-friendly products with fewer organizational resources.	Strives for customer satisfaction with a focus on reducing defects.

Firstly, considering the focus, Lean Production is an approach to enhance industrial performance by minimizing waste. This methodology systematically identifies and removes activities that do not contribute value to the product, optimizing operations and increasing efficiency. In contrast, Green Technology improves ecological efficiency by increasing energy utilization efficiency. This involves adopting environmentally sustainable practices and reducing the ecological footprint of production processes. On the other hand, Six Sigma aims to enhance performance by reducing defective parts.

By employing statistical tools and quality management techniques, Six Sigma minimizes variability and defects, ensuring high product quality and process consistency. Regarding competitiveness and profitability, Lean Production seeks to enhance organizational profitability by removing activities that do not add value. This waste reduction lowers operational costs and enhances the firm's market competitiveness. Green Technology, however, aims to enhance competitiveness by minimizing environmental impacts. This appeals to environmentally conscious consumers and involves complying with regulatory requirements, potentially reducing compliance costs. Six Sigma increases competitiveness by delivering high-quality products and reducing the need for rework. Focusing on quality improvement enhances customer satisfaction and reduces costs associated with quality failures, thereby strengthening the firm's market position. In terms of waste reduction approaches, the three methodologies differ significantly. Lean Production focuses on minimizing all types of waste to lower costs. This includes waste in materials, time, and processes. Green Technology emphasizes the reduction of environmental waste.

This involves reducing emissions, conserving energy, and minimizing the use of harmful materials, thereby promoting sustainability. Six Sigma aims at defect reduction, which indirectly reduces rework. By minimizing defects, Six Sigma increases process efficiency and reduces waste in terms of time, materials, and labor. Furthermore, each methodology adopts different approaches to customer orientation. Lean Production aims to reduce costs and enhance customer focus, ensuring customers receive high-quality products at lower prices. Green Technology seeks to increase customer pride by producing eco-friendly products with fewer organizational resources. This approach aligns with consumer demand for sustainable products. Six Sigma aims to achieve customer satisfaction by reducing defects; this ensures the consistent delivery of high-quality products that meet customer expectations. In conclusion, while Lean Production, Green Technology, and Six Sigma each have unique focal points and methodologies, they all contribute to enhanced organizational performance and competitiveness through different mechanisms. Lean Production emphasizes waste minimization and efficiency, Green Technology focuses on sustainability and environmental impact reduction, and Six Sigma concentrates on quality improvement and defect reduction. Despite all the differences, a common feature of the Lean Production view, Green Technology view, and Six Sigma view is their facilitation and support of the implementation of Operational Excellence and Environmental Management (OEEM). These three distinct methodologies have been applied in public institutions. The improvement of the automotive and construction sectors has been analyzed by examining existing processes. Banawi and Bilec proposed a model that integrates Green Technology, Lean, and Six Sigma to enhance the environmental efficiency of the construction sector. This proposal has inspired the development of the methodological framework for our study[34].

3.2. Sustainable Operation Management

In this section, studies from the literature focusing on the development of a sustainable production system and corporate philosophy are reviewed. In this context, through a literature review using the keywords "Sustainability," "Production Management," and "Lean Management," numerous scientific studies in various subtopics have been identified. These subtopics can be outlined as follows:

The relationship between lean design of production systems and sustainability [35-40]; Integration of lean design of production systems with other quality and management approaches: [41-46]; Lean production and economic sustainability [48-53]; Cultural transformation and integration of lean production [53], [33]; and Lean production in conjunction with other business management perspectives [18, 29, 32, 56-66].

Firstly, within the studies under the theme of the lean design of production systems and sustainability, Chen et al. contribute insights into how green practices can be implemented alongside the design of production systems in China [36]. This research examines the influence of Chinese manufacturing companies in driving sustainability efforts, investigating the intricate connections between lean production strategies, eco-friendly, and environmental outcomes. Cherrafi et al. conducted an extensive literature review on integrating lean design, Six Sigma, and sustainability [37]. This review significantly contributes to the literature by facilitating the understanding of existing proposals, identifying research gaps, and outlining future directions. García-Alcaraz et al. focus on a study of the impact of lean manufacturing tools on social, economic, and environmental sustainability in Mexican maquiladoras [65]. Important findings regarding the role of lean manufacturing tools in sustainability are presented using the example of Mexican maquiladoras. Helleno et al. undertook a study on integrating sustainability indicators into Brazil's lean design of production systems [39]. The study identifies economic, social, and environmental factors, presenting novel sustainability indicators relevant to the manufacturing process. Jamwal et al. conducted a long-term (twelve years) observational study on evaluating sustainability trends in the manufacturing sector alongside lean design of production systems [40]. This study provides insights into the impact of Industry 4.0 technologies and suggests future research themes. Another study Jum et al., addresses the relationship between Total Quality Management (TQM), lean design, and environmental sustainability in Jordanian SMEs [41]. The study emphasizes the significance of quality culture as a moderator, highlighting the nuanced interplay between TQM, lean manufacturing, and sustainability, particularly in the context of cultural differences. Examining the contents of these relevant studies reveals how sustainability can be substantiated with concrete indicators as a manifestation of lean production design, supported by theoretical and practical examples.

Secondly, studies on the theme of integration of lean design with other production quality and management approaches are examined. Kaswan et al. address barriers hindering the adoption of green lean Six Sigma for manufacturing sustainability [66]. The study highlights management-related barriers clarified through decision-making trials and evaluations in a decision trial and evaluation laboratory, providing guidance to policymakers aiming to encourage sustainability practices. Kosasih et al. have conducted another study on this theme, involving a systematic literature review focusing on the impact of supply chain sustainability in manufacturing SMEs [43]. The study particularly emphasizes the lack of comprehensive research covering the relationship between lean-green practices and triple-bottom-line performance in the context of manufacturing SMEs.

Longoni and Cagliano present a case study based on a genre, elucidating the effects of cross-functional managerial involvement and worker participation in aligning lean manufacturing practices with environmental and social sustainability [67]. The results of this study emphasize the positive effects of both managerial and worker participation on aligning lean manufacturing practices with environmental and social sustainability. Manmohan and Shalij propose an optimal prediction model for manufacturing parameters to integrate lean, sustainability, and Quality Management Systems (QMS) [45]. The study demonstrates the approach's effectiveness in predicting manufacturing parameters optimally using artificial neural networks and the imperialist competitive algorithm. Milosevic et al. conducted a case study on applying the PDCA cycle through lean manufacturing to achieve sustainability [68]. The findings suggest that implementing lean tools and focusing on increasing efficiency leads to a tangible increase in overall efficiency. In another study, Misopoulos et al. use corporate theory to examine sustainability drivers in manufacturing project management [47]. The study integrates lean and life cycle analysis, emphasizing the necessity of stakeholder and communication management to achieve consistent, sustainable industrial outcomes. In conclusion, the studies within the theme of integrating lean design with other production and quality management systems focus on various aspects of sustainability, such as business systems, organizational structures, business philosophies, social capital, and production efficiency.

Thirdly, scientific research within the theme of lean manufacturing and economic sustainability is considered. Pham and Thomas propose the Fit Manufacturing Framework (FMF) for economic sustainability [48]. This framework, integrating lean and agile principles, emphasizes meeting the demands of mass customization and ensuring long-term economic sustainability. Another study by Piyathanavong et al. investigated the adoption of operational environmental sustainability approaches in the Thai manufacturing sector.

The findings emphasize the importance of investment capacity, appropriate training, and internal motivation for effective sustainability practices [49]. Psarommatis et al. advocate the Zero-Defect Manufacturing (ZDM) method for higher manufacturing sustainability [50]. The study aims to outline the avoidance of errors, provide evidence from the literature, and sketch the ongoing transition to ZDM. Studies that conducted example case analyses under this theme have also been identified. Ramos et al. perform an example case analysis proposing the Lean Cleaner Production Benchmarking (LCPB) method to analyze sustainability practices in Brazil [51].

This method introduces a new approach to evaluating culture and practices related to Clean Production (CP) in Brazilian manufacturing companies. Tong and Huatuco have conducted a case study focusing on the impact of lean manufacturing, culture, and sustainability initiatives in the Chinese automotive industry [51]. This example case study emphasizes the importance of lean principles and cultural dynamics in shaping sustainability initiatives. Tran et al. have conducted a study examining the contradictory relationship between lean manufacturing, sustainability practices, and Triple Bottom Line (TBL) performance in India [52]. Based on survey data from 177 manufacturing firms in India, the study shows an advantageous relationship between Lean manufacturing and TBL performance but also emphasizes the challenges in integrating Lean Manufacturing with environmental and social practices. The final sub-theme encompasses scientific studies on lean manufacturing and other perspectives in business management. The relevant scholarly works in this sub-theme are as follows:

Agrawal et al. have conducted a study highlighting the circular economy movement in Operational Management (OM) research [54]. The study discusses the foundational concepts of the circular economy and draws insights from companies adopting this approach. It identifies promising research questions in OM that are aligned with the circular economy. Agrawal and Ülkü have focused on modular upgradability as a green design strategy [55]. The research examines the role of modular upgradability in maximizing the useful life of specific subsystems and provides relational findings on how this strategy affects a firm's development decisions and environmental outcomes. Ata et al. have conducted a study focusing on optimizing waste-to-energy operations [56]. The research addresses firms that recover energy from organic waste, considering their dual role in waste removal and using waste to generate renewable energy. The findings offer insights into maximizing profitability strategies for waste-to-energy operations by analyzing market characteristics, regulatory mechanisms, and process considerations. Atasu et al. examined a comprehensive literature review of the first 20 years of publications on sustainable operations management [31]. The study provides a general overview of trends in sustainable operations management and evaluates its impact within the field of operations management research.

It also outlines potential future research directions in sustainable operations management. Betcheva et al., introduced an operational management forum that focuses on the thought structure of healthcare supply chains [28]. The study recognizes the complexity of healthcare supply chains, draws lessons from years of supply chain management experiences, and introduces new perspectives for practical application. By offering new insights into coordination, mass customization, and the unique challenges of healthcare supply chains, the study provides alternative perspectives from the traditional supply chain viewpoint. Corbett has conducted a scientific study exploring the connections between operations, happiness, equality, and sustainability [57]. The study organizes operations into five broad areas, concentrating on the impacts of operations on happiness, equality, and sustainability.

The MSOM Fellow forum article emphasizes the multifaceted contributions of operations to individual, societal, and environmental well-being, identifying research directions in operations management. Corbett and Klassen have performed a study advocating for adopting an environmental perspective in operations and its unexpected positive outcomes in two fundamental areas: quality management and supply chain management [58]. The study introduces the concept of the "expected unexpected benefit law," emphasizing that integrating an environmental perspective into operations can lead to unforeseen positive results. De Zegher et al. have addressed the potential for creating shared value in complex supply chains [59]. The study focuses on agricultural value chains, highlighting cases where suppliers are responsible for the costs associated with the new technologies, but buyers primarily reap the benefits. The study offers valuable insights into strengthening responsible supply strategies by determining optimal contract structures and identifying the role of supply channels. Dong et al. have investigated the effects of mobile money services on the value chain, particularly in emerging economies [60]. The research explores interactions between Mobile Network Operators (MNOs), banks, and end-users, highlighting the potential economic benefits of mobile money, especially for elderly, poorer, and less educated populations. The findings identify the potential asymmetry of benefits associated with complementary services such as credit payments. Drake and Spinler have conducted a study evaluating sustainability flows within operations management [61].

The study discusses key driving forces such as population growth, resource constraints, and ecological risks, forming the basis for considering sustainability as a management issue. The research explores how operations management can cope with these challenges and suggests criteria for sustaining the momentum of sustainable operations management as both a scientific and practical discipline. Hopp and Spearman have defined the concepts of pull and lean manufacturing [17]. The study contrasts nuanced academic definitions of these terms with the simplified interpretations prevalent in practitioner literature, arguing that such simplifications lead to misunderstandings. Hu et al. have conducted a study examining one-time capacity investments in renewable energy technologies [62]. The research emphasizes the importance of data security in renewable energy production technologies and provides various strategies for optimizing capacity portfolios in the face of random disruptions. Jira and Toffel have explored suppliers' willingness to share information related to climate change [63]. The study identifies factors influencing suppliers' openness to share their sensitivity to climate change and approaches to mitigating greenhouse gas emissions. Analyzing data from the Carbon Dioxide Disclosure Project's Supply Chain Program, the research provides findings into the dynamics of information sharing within supply chains related to climate change.

Krishnan et al. have focused on sustainable product family design [64]. The research delves into the challenges and benefits of developing families of technology-based products. The study emphasizes the importance of using a common product platform to reduce individual product development costs by targeting a market where customers make choices based on product performance. Additionally, a model is proposed to capture product development costs based on different family variants. In summary, the studies within this sub-theme explore diverse aspects of operations management, including circular economy principles, green design strategies, waste-to-energy optimization, sustainable operations management trends, healthcare supply chain complexities, the interplay of operations with happiness, equality, and sustainability, environmental perspectives in operations, creating shared value in supply chains, the effect of mobile money on the structure of value chains, and the definitions of pull and lean manufacturing concepts. Each study provides valuable insights and contributes to the broader understanding of sustainable operations management from various perspectives.

In conclusion, the review covered the content of scientific studies under five distinct sub-themes. The analysis reveals that numerous case studies have been conducted in both the manufacturing and service sectors focusing on sustainability. However, it was noted that the case studies did not address companies engaged in manufacturing related to petroleum and its derivatives, which are crucial for the sustainable preservation of nature. Moreover, limited research has been conducted in the South American region, and there is a lack of scientific studies on sustainability-focused manufacturing in Peru. Besides, the barriers to adopting this sustainability-based approach are mainly resistance to change, technical challenges in integrating the tools, and the impact on organizational culture. Additionally, sustainable practices impact consumers as they raise environmental awareness, encouraging companies to commit to sustainability with cleaner manufacturing processes; environmental organizations work in partnership with companies to promote greener practices, even using them as role models for other sectors to follow the same path. Therefore, the study's focus on a unique case analysis, along with the distinctive features of the example, is deemed to fill an important gap in the existing literature.

4. Research Methodology

The 5S methodology, originating in Japan and anchored in five principles, each denoted by the letter "S", embodies a systematic approach to process improvement, complemented by continuous enhancement known as Kaizen [69]. In the short term, this methodology enhances process efficiency with expected outcomes, rendering it a viable system for companies with multiple processes [70].

Numerous authors highlight the efficacy of the 5S methodology in worker training. Its objectives include standardizing work procedures, facilitating the identification of process abnormalities, and streamlining their subsequent elimination [71]. Over the years, this tool has effectively addressed various company challenges. For instance, a plastic manufacturing company experiencing delays in the assembly area due to extended material search times successfully improved its productivity. This involved seven months of total worker participation, resulting in a noteworthy reduction in material search time from 5 hours per month and increased productivity from 75 to 100 percent [70]. Conversely, another company within the same industry encountered waste-related issues impacting the operational efficiency of the blow molding and printing processes. Strategic interventions led to significant reductions, decreasing waste from 12.12 to 8 percent in the blow molding process and from 34.78 to 18 percent in the printing process [71]. A pertinent case study unfolded in a small-scale manufacturing industry grappling with high waste rates. Productivity languished at 60 percent due to prevailing issues, prompting workers to proactively enhance the work environment. Post-implementation, there was a notable 55 percent increase in productivity within the first year [72].

Total Productive Maintenance (TPM) is a continuous improvement system originating from Japan, designed to significantly increase production in a company while boosting employee motivation [5, 30]. This philosophy involves engaging human capital at all levels for sustained operational effectiveness[87]. In numerous studies, Overall Equipment Effectiveness (OEE) is a critical metric for evaluating performance after implementing this lean tool [74]. OEE is subdivided into three leading indicators: availability, representing the equipment's operational time; performance, comparing actual production to planned production; and quality, measuring operating time against expected outcomes [7].

A specific case study within this research occurred in a plastic injection company facing challenges from frequent machine breakdowns. Initially, the average OEE for the process stood at 50 percent. The authors focused on this particular process due to its industry significance. A planned maintenance proposal was implemented to address the issue of two malfunctioning machines. Results indicated efficiency increases of 11.43 and 9.2 percent for both pieces of equipment after TPM implementation [7]. In another study conducted in Malaysia, issues such as excessive reprocessed products, bottlenecks, and delays in delivery times were identified. To address these challenges, the authors applied the philosophy of autonomous maintenance combined with continuous improvement through Kaizen. The assessment included three key indicators: variability, current productivity, and plant performance. Results showed a 33 percent reduction in cycle time and a 6.3 percent decrease in processing time, aligning with the researchers' expectations [74].

Additionally, a notable case study highlighted the application of the total productive maintenance philosophy with a continuous improvement approach in a company manufacturing PVC pipe product. The issue revolved around customer dissatisfaction due to products not meeting specifications. The OEE indicator, initially measured at 55.45 percent, prompted the authors to reference a global study within the same sector, revealing a 60 percent gap. Following the implementation of this methodology, the indicator improved to 68 percent, surpassing the gap. In essence, this contributed to reduced product rejections and increased customer satisfaction [75]. Single-Minute Exchange of Die (SMED), a technique to reduce setup times in manufacturing, is a lean manufacturing method designed to achieve significant cost savings [30]. The aim is to minimize setup times to a single digit, ideally less than 10 minutes [76]. Originating from the need to reduce batch size in a Japanese company, it was implemented [77]. The method includes crucial concepts like changeover time from one product to another during equipment downtime [78]. Another critical concept is operation preparation, identified as a non-value-added activity [79]. These preparations are categorized as internal and external setups, with researchers often suggesting transforming internal setups into external setups while the machine is operational. Several authors have successfully applied SMED in practical scenarios to yield positive outcomes. For instance, in a case addressing overproduction in the screw cap process, high setup times constituted 27.7 percent of the total time. The proposed SMED implementation resulted in a 15 percent reduction in cutting times, 88 percent in printing, and 68 percent in knurling.

Additionally, the initiative saved 180m2 of space within the plant [77]. In another study by Parwani and Hu, unproductive times associated with changing plastic parts in a rotary thermoforming machine were identified, causing a daily loss of 165 minutes across three shifts [80]. The proposed solution reduced setup times through five phases: measurement, addressing unnecessary delays, transforming internal activities into external ones, eliminating non-value-added activities, and standardization. As a result, setup times were reduced to 9 minutes per shift, accompanied by a 6 percent decrease in programming costs. This research model is built upon lean tools to enhance the injection process's efficiency and elevate the company's service level.

The foundation of this proposal stems from a 2022 study where methodologies like 5S, SMED, TPM, and Jidoka were employed to optimize the operations of a plastic injection production company [5]. After reviewing multiple studies, weight was assigned to the most frequently utilized lean tools.

Figure 1 illustrates that SMED is prominently featured (26.92 percent) in research studies to minimize setup times in production lines. Additionally, 5S and TPM tools are combined in 19.23 percent of cases, working synergistically to meet the defined objectives. Likewise, other tools such as VSM and continuous improvement Kaizen play roles in identifying issues within critical processes and proposing action plans with minor adjustments.

Figure 2 presents an innovative model developed by Quiroz and Vega to address the issue of order non-compliance arising from machine breakdowns and excessive setup times in a plastic industry company [10]. The proposal involves specific stages, defining input and output indicators. Additionally, anticipated benefits are outlined after the implementation of improvement tools.

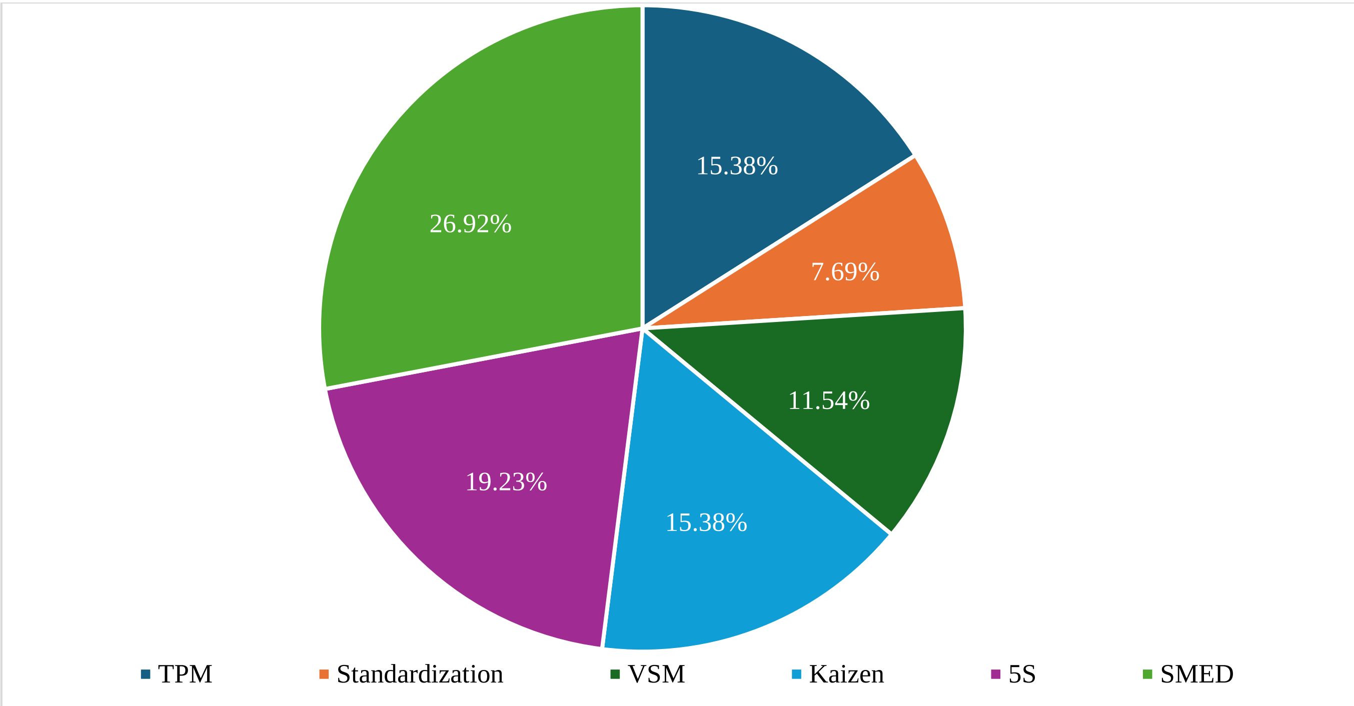

Fig. 1 Weighting based on researched tools

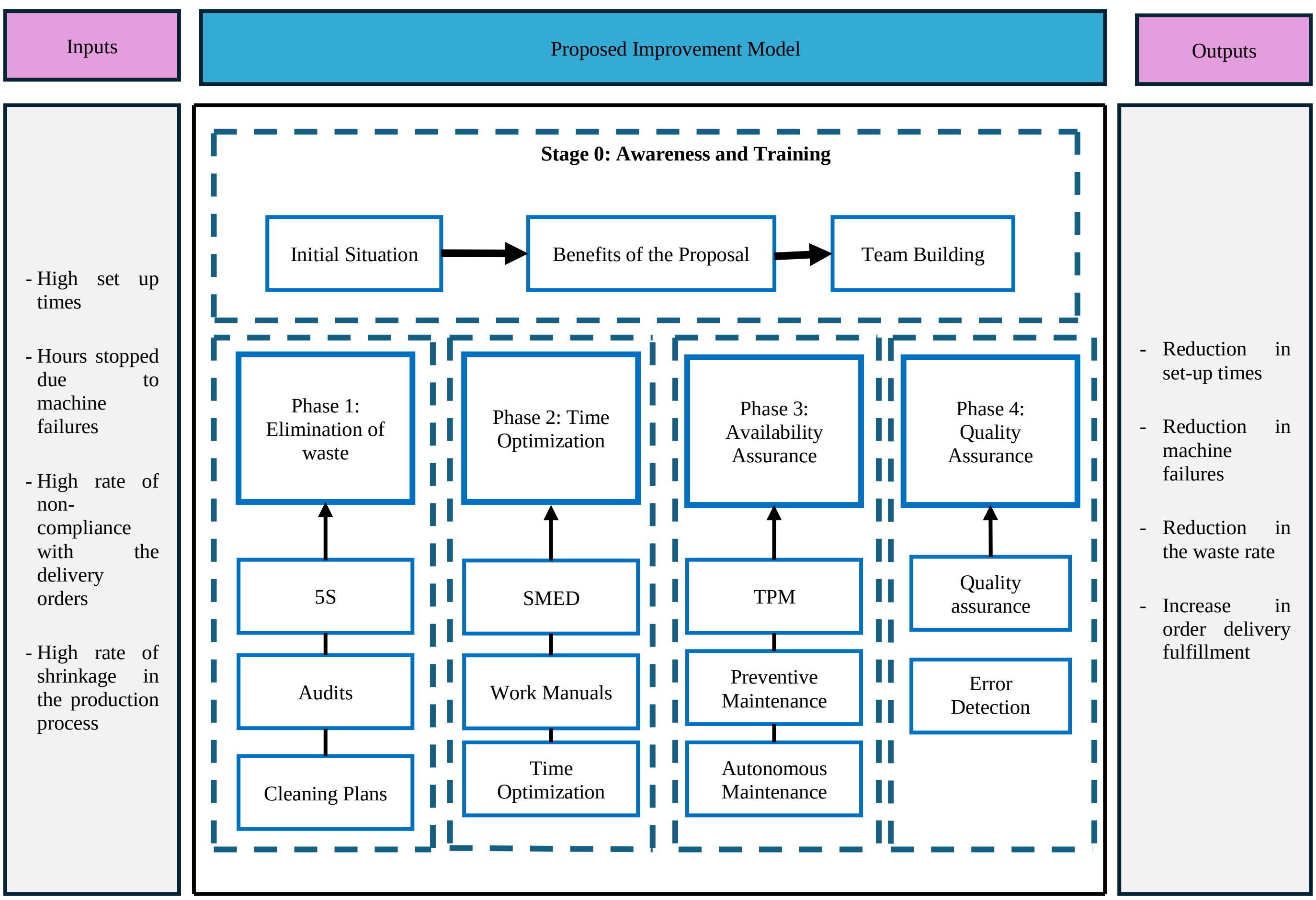

Fig. 2 Proposed improvement model

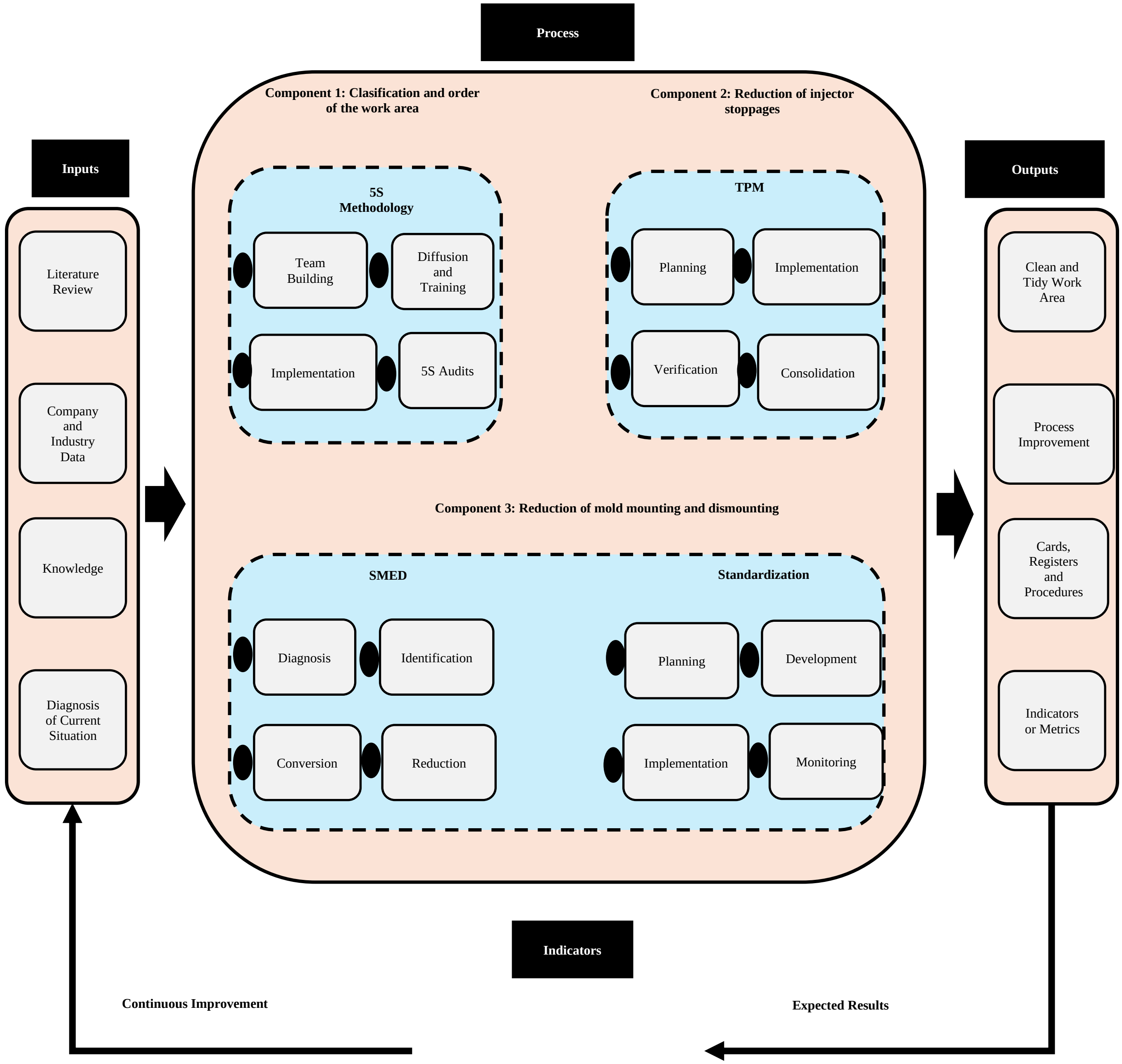

Fig. 3 Proposed model

`To better grasp how this model operates, consider a real-world scenario. A plastic manufacturing company faces persistent challenges meeting order deadlines due to machine breakdowns and extended setup times. Quiroz and Vega's model is implemented to overcome these difficulties, directing the systematic integration of lean tools such as 5S, SMED, TPM, and Jidoka to enhance operational efficiency [5]. As a result of this implementation, the company significantly reduces machine breakdowns and setup times.

For instance, initially, obstructive setup times in the production process are markedly decreased, leading to a more streamlined workflow. This, in turn, improves order compliance by enabling the production line to consistently meet customer demands without unnecessary delays.

The input and output indicators specified in the model play a critical role in monitoring and evaluating the effectiveness of the applied tools. Metrics such as reduced downtime and increased production output are tangible indicators of the model's success. The authors' careful definition of anticipated benefits facilitates a clear understanding of the positive impact of implementing lean methodologies.

Similarly, a study conducted by Mahmoud and colleagues introduced a novel concept called Operational Equipment Comparison Level (OECL), built upon the foundation of Overall Equipment Effectiveness (OEE) [81]. This concept aims to enhance efficiency in industries, enabling the comparison of different machine types, capacities, and operational costs. To achieve this, they employed a mathematical linear approach for data analysis, thereby improving process performance [81]. To illustrate the practical implications of Mahmoud's study, let's consider a manufacturing scenario with various machines of different capacities. Before introducing the OECL concept, evaluating these machines' overall effectiveness and cost implications could be challenging.

However, the implementation of OECL facilitates a systematic comparison that includes factors such as machine efficiency, capacity utilization, and associated operating costs. For instance, a specific type of machine might exhibit a higher OEEM. However, it may not be the most cost-effective option in an evaluation incorporating OECL and integrating operating costs. The mathematical linear approach used in data analysis offers a detailed understanding of the performance landscape. This assists decision-makers in selecting machines that demonstrate high efficiency while aligning with budget constraints and overarching operational goals. In this manner, Mahmoud's study demonstrates how OECL can be practically applied in industries. It sheds light on the value of OECL as a valuable tool in decision processes related to machine selection and process optimization. Integrating concrete examples contributes to a better understanding of how OECL is a valuable asset for industries striving to enhance overall effectiveness. In Figure 3, we can observe the improvement proposal developed within the scope of this research; this proposal includes inputs derived from data collections conducted to diagnose the company's situation. Additionally, we can see the outputs observed after implementation; these consist of clean and organized work areas, improved processes, and records. To illustrate the practical results of this improvement proposal, let's consider a concrete scenario. Imagine a manufacturing company grappling with challenges in productivity and organization linked to disorganized processes and cluttered workspaces.

The improvement plan depicted in Figure 3 encompasses a systematic approach. Before implementation, the data collection conducted within the company involves examining existing work areas, inefficiencies in workflow, and documentation practices. For instance, observations might reveal the presence of unnecessary items in work areas, leading to delays and confusion. Instances where processes lack standardization can result in inconsistencies and errors. Following implementation, the results manifest as notice- able changes in the work environment. Work areas are now clean and organized, creating a more efficient and visually transparent workspace. Processes have been improved based on lean principles, reducing delays and errors. Implementing standard documentation practices ensures accurate record-keeping, aiding future assessments and continuous improvements. This example provides a concrete context for the improvement proposal, showcasing how specific problems were identified and addressed through the proposed methodologies. Integrating real-world examples enhances reader understanding and makes academic findings more relevant and applicable.

4.1. Re-Engineering of Business Processes Involved in Production Activities

Among the lean manufacturing tools utilized in this project are 5S, TPM, and SMED, which specifically emphasize standardization. The implementation of the 5S methodology is structured into four phases within the workspace. In the initial stage, a team led by the production manager is assembled to ensure the realization of predetermined objectives. Subsequently, the dissemination phase follows, where subject matter experts provide necessary training. The third phase, implementation, involves making the tool operational and is further divided into two subcategories for each concept. In the first" S," Seiri, the classification of tools or essential elements in the workspace is carried out to reduce costs. In the second" S," Seiton, the emphasis is on promoting order to provide a suitable place for subsequent use or storage, thereby enhancing productivity. The third" S," Seiso, focuses on general cleaning to improve efficiency in the injection process.

Additionally, the fourth and fifth" S" are implemented at each step to standardize processes and identify potential improvements based on continuous improvement. Following these stages, audits are conducted to assess the impact of these tools and compare the results with the project's initial state. In summary, the 5S methodology instils discipline in the work environment through classification, order promotion, and meticulous cleanliness.

This structured approach, supported by ongoing evaluations, facilitates adherence to standards and perpetuates the continuous improvement of operational excellence. Transitioning to the second component, the Total Productive Maintenance (TPM) tool is similarly divided into four phases. The initiation involves planning and disseminating the tool in the workspace, forming a TPM team led by the maintenance manager, and having technicians and operators play crucial roles in machine maintenance. The second phase encompasses the tool's implementation, with training sessions focusing on autonomous and preventive maintenance principles throughout the process. Instruction sheets utilize green and blue colors to highlight machine failures' severity and complexity. A program is employed to control activities during this stage, and in the third verification phase, supervisors ensure assigned tasks are completed in their respective areas.

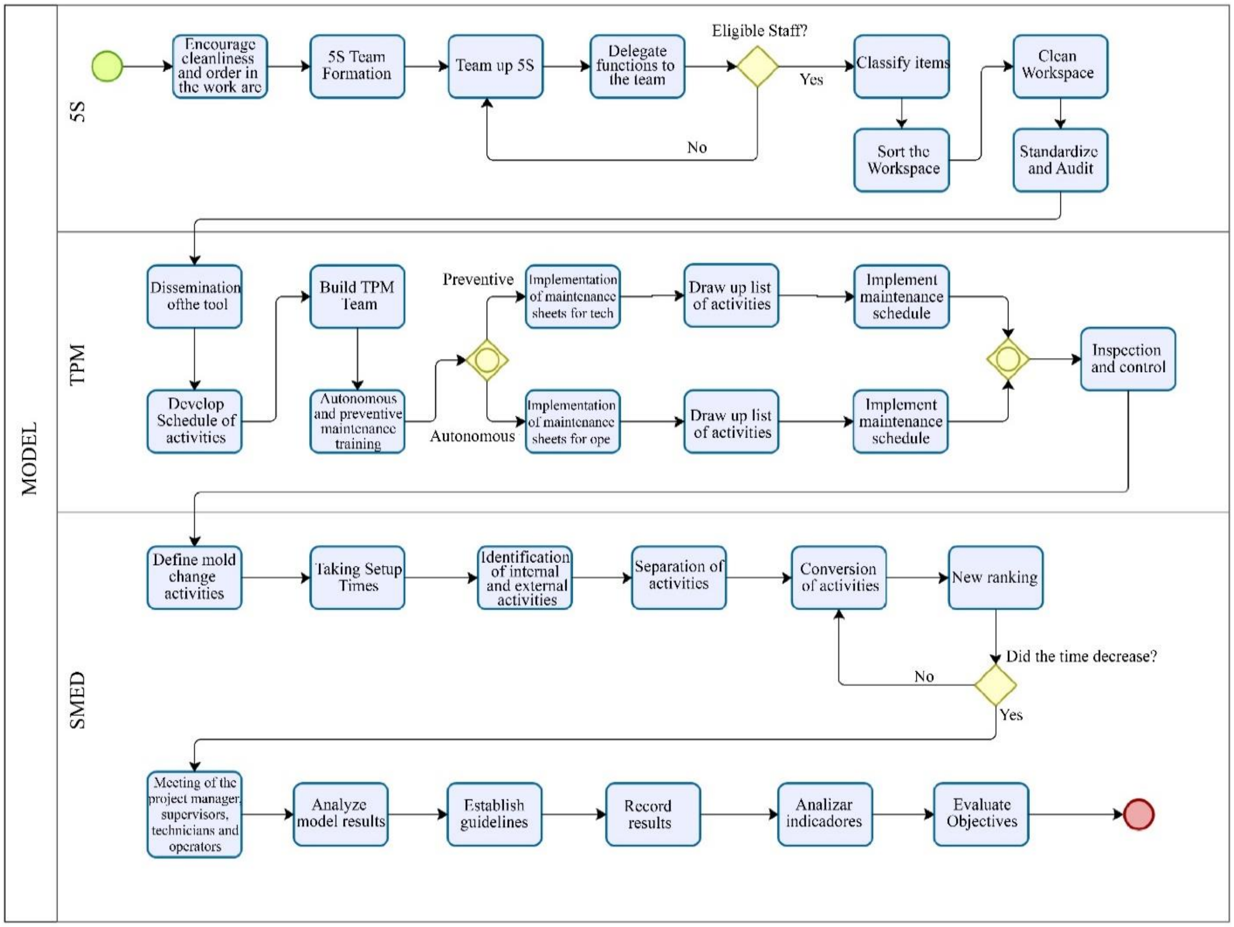

Fig. 4 Detailed model

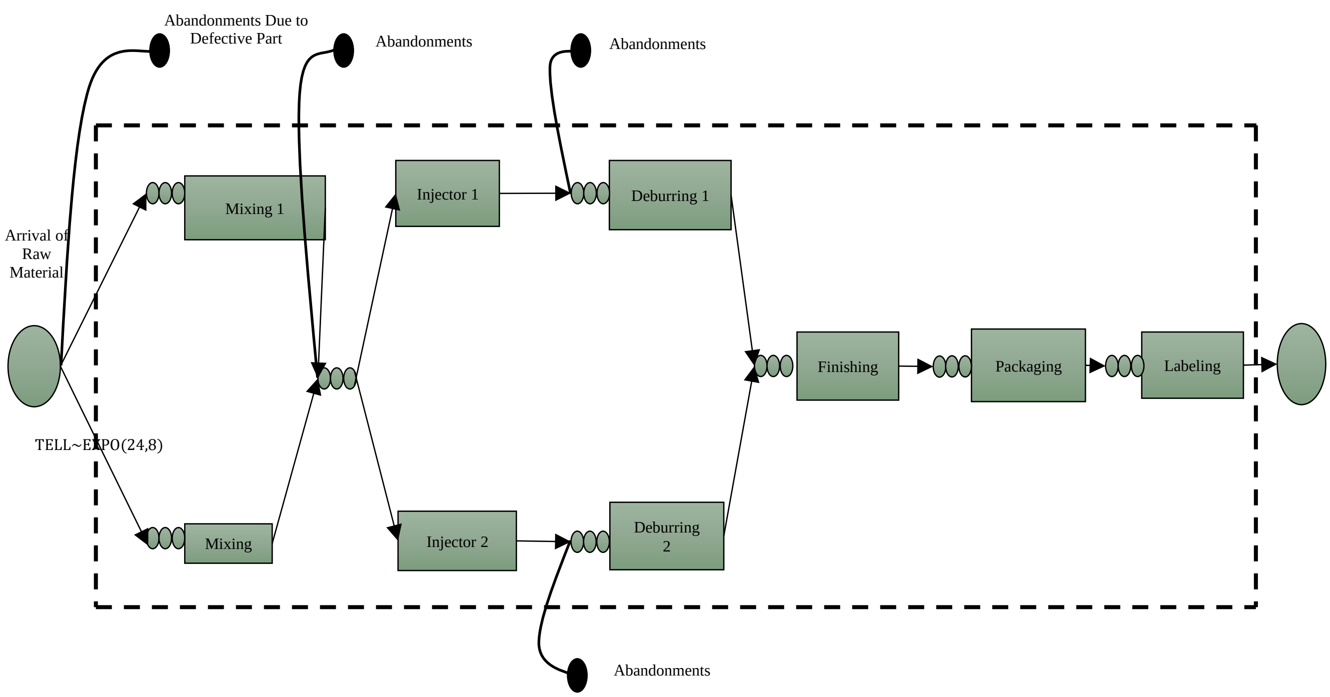

Fig. 5 Representation of the system

Documentation is utilized to record implementation progress for enhanced control. In the final phase, the entire team undergoes maintenance audits. Mean Time to Repair (MTTR) and Mean Time Between Failures (MTBF) indicators gauge results obtained from the initial situation and after implementing the tool. Any errors are recorded for prompt resolution. Moving on to the final component, two lean tools, SMED and general Standardization, are complemented. In Figure 4, we can see the detailed model. The initial phase involves diagnosing a list of activities, primarily related to mould assembly and disassembly, and timing the execution of these setup activities. Subsequently, activities are categorized into internal and external setups, with the former conducted while the machine is running and the latter when it is stopped. The next phase is conversion, where internal activities are transformed into external ones, aiming to reduce unproductive time by introducing additional support personnel. Standardizing the previous tools is also undertaken. A procedure card is proposed, utilizing results from the initial trial, for dissemination within the work area. Additionally, monitoring is conducted using Overall Equipment Effectiveness (OEE) indicators based on a literature review and the company's current situation.

4.2. The Scenario

The examined company operates in the plastic industry in Lima, featuring five production lines: furniture, cleaning, kitchen, agribusiness, and organizers. The critical process for the company is the injection molding process. The measurement of its effectiveness indicates that the injection molding machine functions at an efficiency rate of 53.1 percent. However, industry standards for similar processes reflect an efficiency indicator of 68.3 percent. This discrepancy has an economic impact, constituting 19.38 percent of the total annual sales. Consequently, the company implemented Lean tools such as 5S, TPM, and SMED, yielding positive results.

This analysis focuses on a Lima-based plastic industry company with diverse production lines, including furniture, kitchenware, cleaning products, organizers, and agribusiness. The critical operational process within the company is the injection molding process. Efficiency measurement of the injection molding machine revealed an effectiveness level of 53.1 percent, while industry standards for similar processes show an efficiency indicator of 68.3 percent. This gap has significant economic implications, constituting an economic impact of 19.38 percent of the company's annual sales. The economic importance underscores the urgency and significance of addressing inefficiencies in the injection molding process. The company implemented strategic measures to rectify this situation by applying Lean tools such as 5S, TPM, and SMED. These tools were systematically employed to enhance operational processes and efficiency in injection molding. The results indicate a notable improvement in effectiveness, surpassing the initial 53.1 percent level.

Table 2. The scenario's technical gap

Indicator	Percentage Values		Difference
	Case Company	Plastic Industry	
OEE	53.1%	68.3%	15.2%

This substantial increase in operational efficiency narrowed the gap between the company's performance and industry standards. It generated positive economic effects, positioning the company more competitively in the plastics industry, as shown in Table 2. In summary, implementing Lean tools effectively addressed inefficiencies in the injection molding process. Adopting a comprehensive approach encompassing 5S, TPM, and SMED, the company successfully increased operational efficiency, resulting in tangible economic impact and enhancing its competitiveness within the industry. In addition, we developed an empirical model aiming to show that increasing efficiency in business processes yields results beneficial to sustainability, and we present the results by calculating them using the variables of the case study company. This case study demonstrates the practical application of Lean methodologies to significantly improve operational performance and economic and sustainability outcomes. The subsequent section presents findings from the three different lean management analysis methods, each enhancing efficiency in the examined manufacturing company.

4.3. Detailed Model

In Figure 3, the proposal for improvement for this research is shown, starting with the data collection from the company and leading to the assessment of the current situation. Furthermore, the results after implementation are presented, which include cleaner and more organized workspaces, improved processes, and records.

4.3.1. Improving Workplace Organization

The lean manufacturing tools used in this project are the 5S, TPM, and SMED - Standardization, which are divided into components. Firstly, the 5S is implemented in the work area, which is divided into four phases. In the first phase, a team is formed, led by the production manager, who will ensure the objectives are met. Then comes the second phase of dissemination, where an expert in the field will provide training. The third phase is the implementation, which involves putting the tool into action. It is further divided into two categories for each concept. In the first "S," Seiri, the classification of tools or necessary elements in the work area is done to reduce costs. In the second "S," Seiton emphasizes the promotion of order to have an appropriate place for subsequent use or storage to increase productivity. The third "S," Seiso, focuses on general cleaning to enhance efficiency in the injection process. In addition, the fourth and fifth "S" will be implemented at each step to standardize and identify potential improvements based on the concept of continuous improvement. Finally, audits are conducted to assess the impact of these tools and compare them to the initial situation.

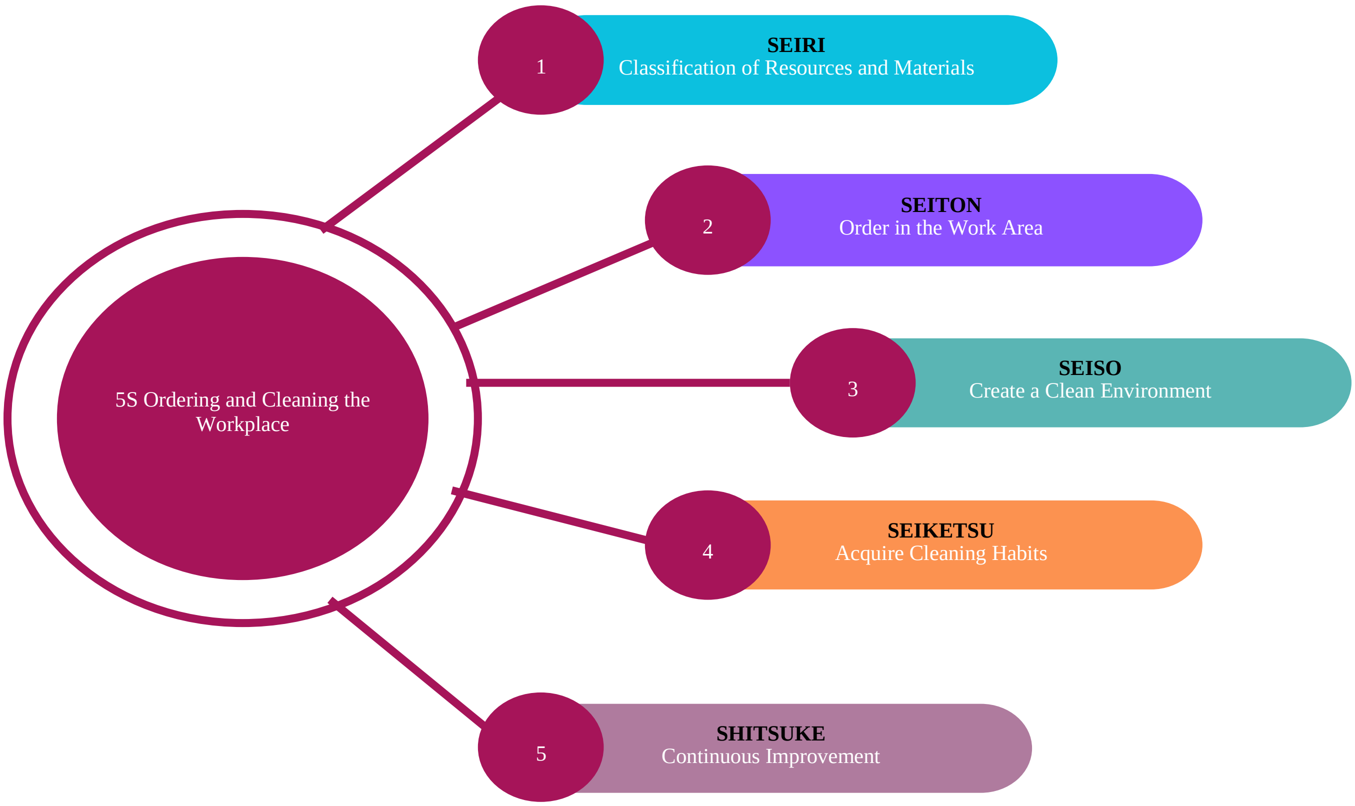

Fig. 6 Concepts of 5S implementation

4.3.2. Autonomous and Preventive Maintenance

As the second component, the Total Productive Maintenance tool is implemented, which is divided into four phases, similar to the previous one. It begins with the planning and dissemination of the tool in the work area.

In this phase, a TPM team is formed and led by the maintenance manager. The main resources are technicians and operators, who are essential in machine maintenance. On the other hand, in the second phase, the tool itself is implemented.

Training sessions are scheduled throughout the process, focusing on autonomous and preventive maintenance pillars. Instruction sheets are created, highlighting machine failures using green and blue colors to indicate the severity and complexity of the problem. Additionally, a schedule is used to control the activities during this stage. In the third verification phase, supervisors inspect and ensure assigned tasks are completed in their respective areas.

Documentation is used to record the progress of the implementation for better control. In the final phase, the entire team is evaluated through maintenance audits. The Mean Time to Repair (MTTR) and Mean Time Between Failures (MTBF) indicators are used to measure the results obtained from the initial situation and after implementing the tool. In case there are any errors, they are recorded for prompt resolution.

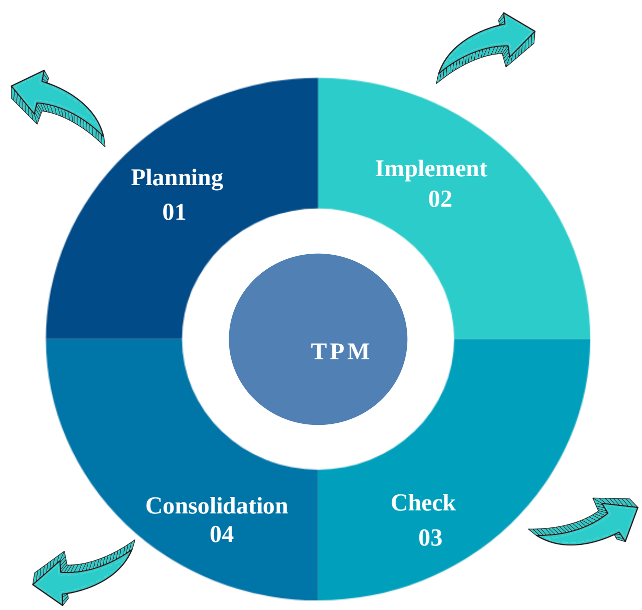

Fig. 7 Phases for TPM implementation

4.3.3. Reduction of setup times

In the final component, two lean tools, SMED and general Standardization, are complemented. The first phase involves diagnosing a list of activities, mainly related to mold assembly and disassembly, and timing the execution of these setup activities. Then, the activities are separated into internal and external setups, with the former performed while the machine is running and the latter when it is stopped. The next phase is conversion, where internal activities are transformed into external ones. The objective is to reduce unproductive time by increasing manpower and introducing an additional support operator. Standardizing the previous tools is also carried out. A procedure card is proposed, using the results from the initial trial, for dissemination within the work area. Additionally, monitoring is conducted using Overall Equipment Effectiveness (OEE) indicators based on a literature review and the company's current situation.

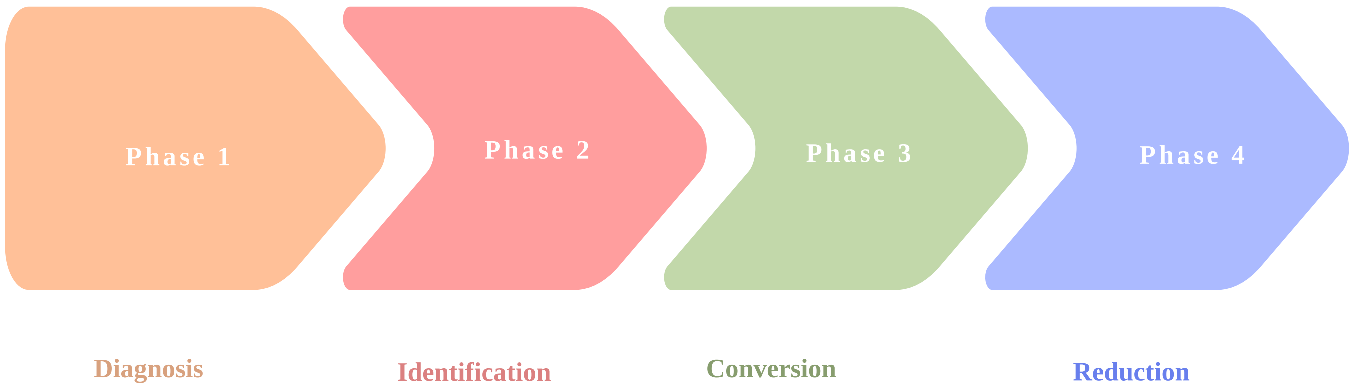

Fig. 8 Phases of SMED implementation

5. Results

The findings section encapsulates the experimental outcomes of implementing Lean management methodologies in the examined manufacturing company. This section provides a detailed analysis of the data collected while applying Lean tools such as 5S, TPM, and SMED.

Subsequent paragraphs comprehensively assess the company's increased operational efficiency, economic impact, and competitive positioning through implementing these methodologies. This section aims to elucidate specific areas influenced by the application of Lean principles by systematically and meticulously explaining the notable improvements in company performance.

5.1. Validation of the Current Situation

To enact Lean Manufacturing successfully, unwavering commitment from all company members is essential, fostering a culture of continuous improvement across all facets [77]. The sequential application of each Lean tool is meticulously executed in adherence to their respective stages, ensuring favorable outcomes [30]. A thorough examination was conducted using Arena software to validate the proposed 5S, TPM, and SMED enhancements. This invaluable simulation tool enables users to experience real-world scenarios effectively and safely through configuration adjustments [82].

This graphical depiction determines each entity's distribution from the arrival of raw materials to the product's labelling. The Input Analyzer was employed to analyze adjustment graphs with samples of at least 150 elements, considering the company's current data for each entity. These elements correspond to random variables detailed in Table 4.

Table 3. Description of random variables

Variables	Description
TBA	Time between arrivals
OT MIX I	Operating time mixer I
OT MIX II	Operating time mixer II
OT INJ I	Operating time injector I
OT INJ II	Operating time injector II
OT DEB I	Operating service time deburring I
OT DEB II	Operating service time deburring II
OT FIN	Operating service time finishing
OT PAC	Operating service time packing
OT LAB	Operating service time labeling

Each random variable conforms to a probability distribution represented by a fitting in Figure 9, potentially following a Normal, Exponential, Uniform, Erlang, or Empirical distribution.

5.2. Initial Diagnostic

The sample size was initially determined for the validation of the existing situation. However, to conduct meaningful simulations, it is crucial to establish indicators that define the appropriate number of replicates. In the study context, the units of measurement observed are in individual pieces and batches of pieces.

After the deburring process, the pieces are organized into batches of 10 for subsequent finishing, packaging, and labelling processes, as illustrated in Figure 10. Each OEE effectiveness parameter and the order fulfilment level were validated based on the graphical representation proposed for the system.

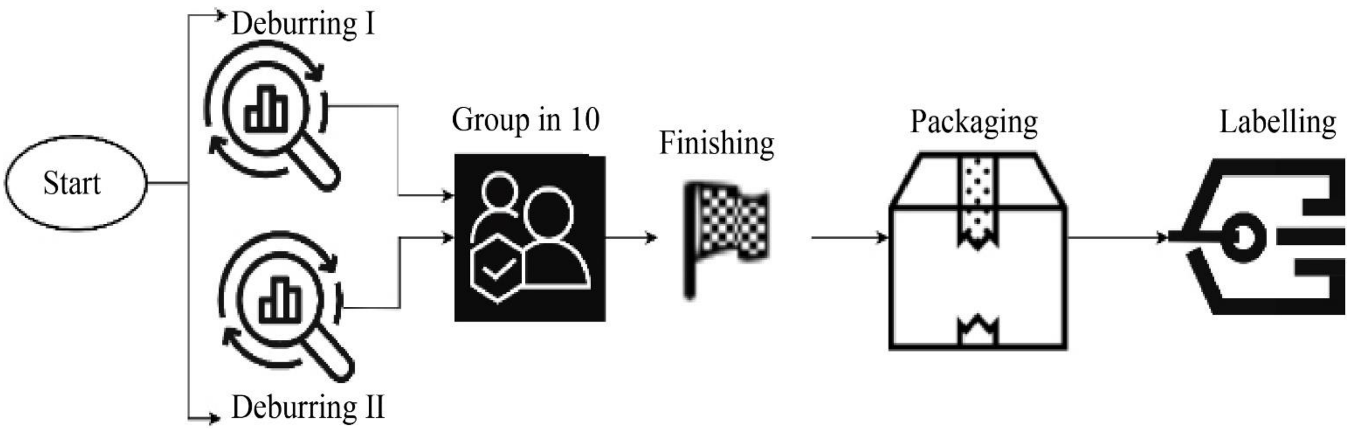

Fig. 9 Grouping in batches of 10 after the deburring process

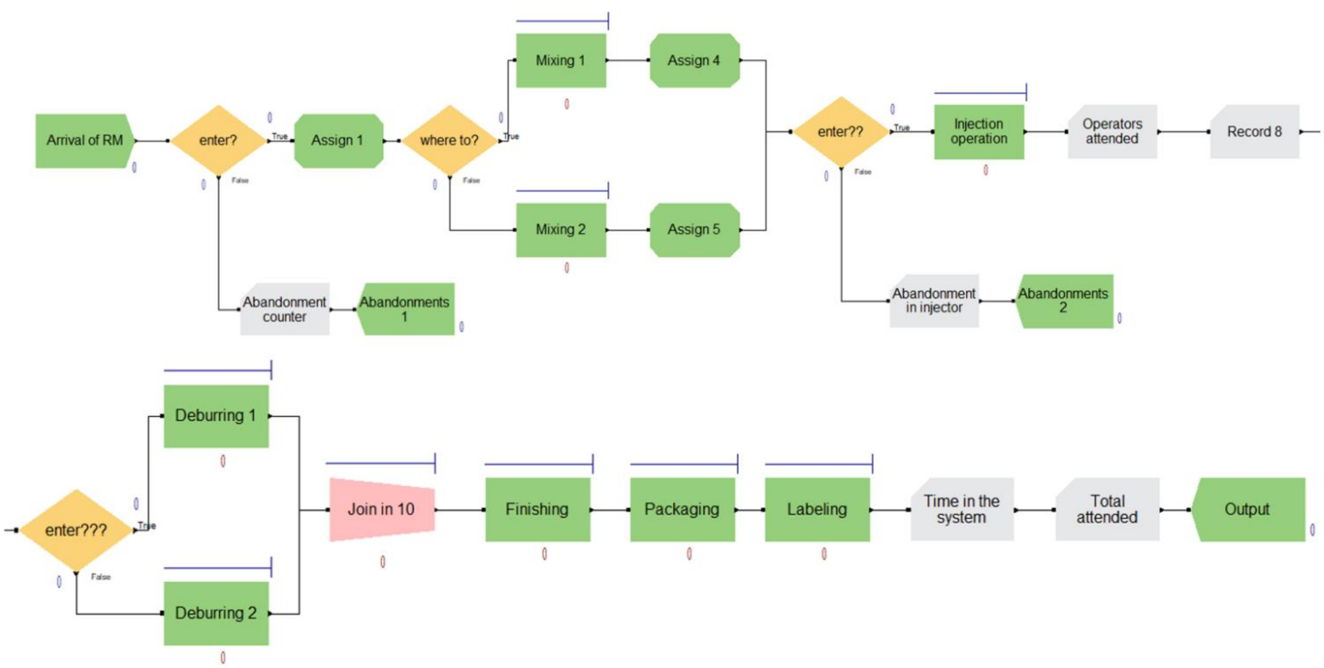

Fig. 10 Graphical representation of the system in the arena simulation software

The Run Setup configuration was determined for a simulation period of 30 days, with 20 hours each day, aligning with the company's operational schedule of 2 shifts, each lasting 10 hours. The primary focus of the analysis centers on the injection molding process, aiming to enhance the efficiency of the injection molding machine. The configuration for this process is vital for evaluating the effectiveness indicator. The current situation reveals that the average time for a batch of parts in the system is 5.3347 minutes, with a service level of 78.82 percent. Additional results include the number of abandonments due to defective parts in the injector and the attended and unattended parts in the injector. The results obtained facilitate the calculation of the OEE effectiveness indicator (4), encompassing parameters such as availability (1), performance (2), and quality (3). The assessment of the issue will be conducted using the suggested indicators, which will assist in measuring its performance or progress to achieve enhancements.

$$\text{Availability (\%)} = \frac{\text{Actual operating time}}{\text{Planned production time}} \quad (1)$$

$$\text{Performance (\%)} = \frac{\text{Design cicle time} \times \text{Output}}{\text{Operating time}} \quad (2)$$

$$\text{Quality (\%)} = \frac{\text{Good parts produced}}{\text{Total parts produced}} \quad (3)$$

$$\text{OEE (\%)} = \text{Availability} \times \text{Performance} \times \text{Quality} \quad (4)$$

The detailed breakdown of each parameter for the current situation is provided in Table 4. The results obtained above help to calculate the OEE effectiveness indicator, whose parameters are availability, performance, and quality. The OEE effectiveness indicator is computed with parameters, including availability, performance, and quality; as demonstrated in Table 4, availability is determined to be 68.47 percent, indicating operational stoppages. Performance is 82.04 percent, suggesting the machine is not operating at total capacity. Quality stands at 96.74 percent, meaning optimal performance in producing defect-free pieces. In conclusion, the critical parameters for improvement in the current situation are availability and throughput, aiming to enhance the injection molding machine's overall effectiveness, currently standing at 54 percent.

Table 4. The current situation of operation results

Variables	Count	Average
Results of the Current Situation	Average time of a piece in the injection moulding machine	0.5614 min
	Number of abandonments due to defective parts	2514.93 pieces
	Number of parts attended in the injector	74563.60 pieces
	Number of parts not attended in the injector	6576.30 pieces
Availability	Actual operating time (min)	49300 min
	Planned production time (min)	72000 min
	Availability (%)	**68.47%**
Performance	Average time of each piece in the injection machine (min)	0.5614 min
	Number of pieces left in good condition (pieces)	72048.67 pieces
	Actual operating time (min)	49300 min
	Performance	**82.04%**
Quality	Number of pieces processed in the injection molding machine (pieces)	74563.60 pieces
	Number of pieces abandoned due to defects (pieces)	2514.93 pieces
	Total number of pieces left in the injection moulding machine (pieces)	77078.53 pieces
	Quality (%)	**96.74%**

5.3. Validation of the Proposed Model

For the envisioned situation, the system is configured by implementing preventive and autonomous maintenance schedules, assigning time for orders, and cleaning the injection molding machine, all within a specified time frame. The critical enhancements outlined in the proposed model are detailed below:

- A daily autonomous maintenance period of 1 hour is recommended.
- Weekly preventive maintenance lasting 5 hours is proposed.
- A daily cleaning duration of 45 minutes is suggested for the injection molding machine.
- It is recommended that the injection machines operate with two operators simultaneously to enhance task-handling efficiency.

In this context, three scenarios were proposed, characterized as pessimistic, typical, and optimistic. Each scenario evaluates the improvement of the OEE indicator for the injector from a distinct perspective. Another significant indicator within the proposed model is the service level, measuring the enhancement across all processes, including the production of plastic products. A slight increase is observed in the studied parameters in the pessimistic scenario. However, the improvements mainly focus on reducing the average time of parts in the system and increasing the number of pieces handled. On the other hand, in a typical scenario, a 9.21 percentage increase in availability is expected, with performance and quality indicators showing an improvement of 4.65 percent and 0.47 percent, respectively, considering both parameters are in acceptable conditions. In a typical scenario, availability is expected to increase by 9.21 percent, considering the current situation within the company. Similarly, performance and quality indicators show an improvement of 4.65 percent and 0.47 percent, respectively, considering that both parameters are in acceptable conditions. Finally, in an optimistic scenario, availability could reach 80.73 percent, performance could reach 93.94 percent, and quality would be maintained in optimal conditions. This would result in a total improvement in the studied parameters. However, it is imperative to determine if the expected gains justify the investment made in the proposed improvement model. We show detailed information about the operation performance in three scenarios in Table 5.

Table 5. Comparison between three different scenarios

	Pessimistic Scenario	**Typical Scenario**	**Optimistic Scenario**
Count	**Average**	**Average**	**Average**
Actual operating time (min)	51149.05	55927.74	58124.89
Planning production time (min)	72000	72000	72000
Availability	71.04%	77.68%	80.73%

Average time of each piece in the injection machine (min)	0.5152	0.5144	0.5062
Number of pieces left in good condition (pieces)	84838.90	78916.70	83206.17
Actual operating time (min)	51149.05	55927.74	58124.89
Performance	85.45%	86.69%	93.04%
Number of pieces processed in the injection moulding machine (pieces)	87222.16	85288.59	83206.17
Number of pieces abandoned due to defects (pieces)	2383.17	2446.93	2383.17
Total number of pieces left in the injection moulding machine (pieces)	89605.33	87735.52	85859.34
Quality	97.34%	97.21%	97.22%
OEE (%)	59.09%	65.46%	73.73%
Service level (%)	81.13%	84.06%	86.74%

6. Discussion

Considering the outcomes derived from the ARENA simulator, the ensuing table delineates affirmative alterations for each of the three envisaged scenarios. The pessimistic scenario notes the minimal adjustment, wherein the OEE indicator shows a 4.75 percentage enhancement, concomitant with a 2.31 percentage augmentation in the service level. In stark contrast, an escalation of up to 19.39 percent in OEE and 7.92 percent in the service level is attainable in the optimistic scenario.

Notably, under the anticipated scenario, both availability and performance could achieve levels of 77.68 percent and 86.69 percent, respectively. Excess setup time is the preeminent cause, accounting for 57.6 percent of the total. The application of the SMED tool aimed at diminishing moulds' mounting and dismounting times in three phases: diagnosis, conversion, and reduction, as shown in Table 6. Each phase involved identifying internal and external activities, transitioning from internal to external, and suggesting optimizations to streamline activities and reduce corresponding durations. This culminated in a reduction from 248 minutes to 117.5 minutes, signifying a 52.62 percent decrease in percentage terms.

A novel sequence of activities was also realized, witnessing a 54.35 percent reduction in the overall number of activities.An analysis of a company engaged in plastic product manufacturing, grappling with persistent order fulfillment issues tied to machine failures and prolonged setup times, witnessed a 39.76 percent reduction through the application of the SMED tool. This underscored the importance of workplace organization and the acquisition of requisite tools for task execution [83].

Another study on an extruder machine encountering protracted setup times during die changes saw a 56.84 percent decrease from the initial 8.99 minutes. This directly translated to an enhanced machine availability by 4.86 percent, leading to a consequential 3.26 percent improvement in the OEE efficiency indicator, a significant outcome for the company [30]. The service level, a metric gauging production or operational capacity concerning customer demands within a specified period, currently stands at 72.82 percent, as shown in Table 7. With the proposed enhancements, a variance between 2.31 percent and 7.92 percent is conceivable. Moreover, the service level is anticipated to reach 84 percent under normal circumstances, equating to an improvement exceeding 5 percent.

Table 6. SMED implementation in three phases

		Phase I Identification	**Phase II Conversion**	**Phase III Reduction**
Activities	Internal	37	27	15
	External	9	19	6
	Total	46	46	21
	Variation			54.35%
Time	Internal	216	102	95.5
	External	32	42	22
	Total	248	144	117.5
	Variation		41.94%	52.62%

Table 7. Improvements in the Level of Service per Scenario

	Service Level (SL)	SL Variation
Current Situation	72.82%	
Pessimistic Scenario	81.13%	2.31%
Typical Scenario	84.06%	5.24%
Optimistic Scenario	86.74%	7.92%

It has been ascertained that both availability and performance parameters are pivotal and warrant improvement. According to Adithya and Anantharaj, implementing TPM resulted in an OEE indicator surge from 57 to 68.4 percents, coupled with reduced injection molding machine failures [7]. Similarly, injection molding machine efficiency burgeoned from 53 to 65.5 percents for the scrutinized company, constituting an approximate 12 percent uptick. Conversely, the SMED tool notably ameliorated setup times by more than 50 percent, a phenomenon corroborated in analogous studies within the same sector and in a separate investigation, the mould change time in a stamping machine plummeted from 25.16 minutes to 12.51 minutes, attaining a 50.3 percent reduction and ensuring a marked improvement in setup time.

Regarding the service level, the envisioned target was a 5 percent enhancement vis-`a-vis the existing scenario; however, the service level exceeded expectations by more than 6 percent. Analogously, a footwear company grappling with a high order non-fulfilment rate experienced an elevation in the service level from 79 to 88 percent through the application of Lean Manufacturing tools [70]. The efficacy of 5S, SMED, TPM, and standardization tools has been substantiated in mitigating a prevalent issue in numerous companies within the plastics industry, namely, the sub-optimal efficiency of injection molding machines integral components of the most critical processes.

7. Conclusion

In conclusion, the application of Lean Manufacturing tools, including 5S, TPM, and SMED, yielded significant improvements in the operational efficiency of the studied company. The injection machine's effectiveness saw a commendable increase from 53.1 to 65.46 percents, with notable enhancements in availability by 7.72 percent and performance by 7.51 percent. The foundational role of the 5S methodology in optimizing the workspace paved the way for successful implementations of autonomous maintenance, preventive maintenance, and SMED. The emphasis on autonomous and preventive maintenance aims to enhance the mean time between failures and reduce repair times, contributing to achieving predetermined goals. Furthermore, the analysis and reduction of prolonged setup times for molding assembly and disassembly resulted in a noteworthy decrease from 248 minutes to 117.5 minutes. These time savings were strategically allocated to increase monthly production by 95,428 units across all injection machines. The collaborative efforts and commitment of all stakeholders involved in the proposal development played a crucial role in achieving a remarkable 6 percent improvement in the overall service level. These multifaceted impacts position the findings as a valuable reference for companies within the industry seeking to optimize their production processes. This study contributes to management science by demonstrating how Lean Manufacturing tools enhance operational efficiency. The observed improvements are benchmarks for companies aiming to streamline their production processes. The strategic allocation of reduced setup times for increased production capacity exemplifies effective resource management, contributing to economic efficiency. The strategic allocation of reduced setup times for increased production capacity exemplifies effective resource management, contributing to economic efficiency. Practical insights into implementing 5S, TPM, and SMED methodologies are provided, offering a real-world perspective on achieving significant improvements in key performance indicators.

7.1. Practical Implications

In this study, relevant data for reconstructing a sustainable operational business process has been analyzed in the ARENA simulator through a case study. The results obtained from this analysis and subsequent discussions provide valuable managerial insights for practitioners in the fields of manufacturing and service operation management. The following strategic implications can guide managers in optimizing operational efficiency and driving improvements across key performance indicators:

7.1.1. Optimizing Operational Efficiency

Proposed scenarios, ranging from pessimistic to optimistic, offer a comprehensive roadmap for managers to optimize operational efficiency. Leveraging insights from the simulation, managers can make informed decisions, aiming for improvements in Overall Equipment Effectiveness (OEE) and service levels. The significant improvements observed in the optimistic scenario guide managers towards achieving optimal performance.

7.1.2. Strategic Application of SMED

The emergence of the Single-Minute Exchange of Die (SMED) tool as an effective strategy for reducing excess setup time is noteworthy. The three-phase approach, covering diagnosis, conversion, and reduction, illustrates how managers can implement SMED to organize activities and decrease setup durations. The reduction from 248 minutes to 117.5 minutes, along with a new sequence of activities, emphasizes the tangible benefits of SMED in minimizing downtime.

7.1.3. Addressing Root Causes

Excess setup time is identified as a primary cause affecting operational efficiency. Managers can proactively tackle this issue by focusing on root causes and implementing targeted solutions. Case studies, including reducing setup times in plastic product manufacturing and extruder machine setups, highlight the importance of workplace organization and acquiring the necessary tools for task execution. Focusing on these root causes can lead to continuous operational improvements.

7.1.4. Improving Service Levels

The discussion section emphasizes the critical importance of service levels in gauging production or operational capacity concerning customer demands. Managers can drive improvements by implementing Lean Manufacturing tools and methodologies, as evidenced by positive impacts on service levels in analogous studies. The potential variance between 2.31 percent and 7.92 percent, along with an anticipated overall improvement exceeding 5 percent, provides a benchmark for managers to set and achieve service level goals, enhancing overall customer satisfaction.

7.1.5. Validating Tool Efficacy

The efficacy of Lean Manufacturing tools, including 5S, SMED, TPM, and standardization, is substantiated in mitigating prevalent issues in the plastics industry. Managers can confidently adopt these tools based on documented successes in improving the efficiency of injection molding machines, which are crucial components in manufacturing processes. The comparative graph visually illustrates the potential improvements achievable through the strategic application of these tools, offering tangible validation for their adoption.

In conclusion, this research provides actionable insights for managers seeking to enhance operational efficiency, reduce setup times, and elevate service levels. By strategically applying Lean Manufacturing tools, managers can navigate challenges and drive substantial improvements in key performance indicators, contributing to the overall success of manufacturing and service operations.

7.2. Limitations and Future Research

With its specific focus on a single-case study and a limited time frame, this research presents meaningful insights for upcoming research in the field of sustainability-focused operational process improvement within the manufacturing industry. However, the study's focused nature inherently imposes limitations. Recommendations regarding research design, sample selection, and alternative research focuses are outlined to guide researchers in future endeavours. Adopting a longitudinal methodology covering an extended period is proposed for future research design. This approach allows for a comprehensive evaluation of the sustained impact of Lean Manufacturing tools on operational efficiency, offering insights based on long-term observations. Additionally, implementing a sample design that facilitates comparative analyses between industries can provide nuanced insights into the advantages and disadvantages associated with implementing lean manufacturing tools in various industrial contexts. This comparative perspective enables researchers to identify industry-specific challenges and tailor Lean methodologies accordingly. Exploring different real-case analyses, particularly in diverse aspects of petroleum derivatives, could contribute significant takeaways into the practical applications of Lean Manufacturing tools in a broader industrial and organizational context.

Such an approach allows for a more thorough analysis of the generalizability and applicability of Lean methodologies across different methods and sample designs. In terms of future research focuses, researchers may delve into areas such as the role of employee involvement and training, integration with Industry 4.0 technologies, nuanced aspects of Lean application, methodologies for perfection, and innovative strategies for continuous improvement in operational performance within the context of sustainability and business efficiency in the manufacturing sector.

Exploring how employee involvement and training influence the effectiveness of Lean practices or studying the integration of Lean Manufacturing tools with Industry 4.0 technologies could uncover new research opportunities. While conducting future research, it is paramount to explore and confirm the generalizability and applicability of Lean methodologies in a broader industrial and organizational context. Maintaining credibility and accurately reflecting the impact of Lean Manufacturing tools should be a priority for future researchers. By paying attention to these aspects, future studies can build upon this study's foundation, contributing to the continuous evolution of manufacturing practices, refining methodologies, and proposing innovative strategies for continuous improvement in operational performance.

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