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PROGRAMA ACADÉMICO DE INGENIERÍA INDUSTRIAL

Propuesta de un modelo basado en 5S, TPM y SMED para mejorar la efectividad en el proceso de inyección en una empresa de plásticos

TRABAJO DE SUFICIENCIA PROFESIONAL

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Dedicatoria

Agradezco profundamente a mi familia por su apoyo constante y por enseñarme con el ejemplo el valor del esfuerzo y la perseverancia. A mis profesores y asesores, por su orientación, consejos y sabiduría durante todo el proceso. Gracias por compartir sus conocimientos y por impulsarme a dar siempre lo mejor de mí. Sin el apoyo de todos ellos, este logro no habría sido posible.

Joe Calderon

Dedico este trabajo a mi madre, por su amor incondicional, su fortaleza y su incansable apoyo; a la memoria de mi padre, cuyo recuerdo sigue siendo una fuente constante de inspiración en mi vida; a mi hermano, por estar siempre presente con su apoyo silencioso pero firme; y a mis profesores, por compartir su conocimiento y por haber contribuido de manera invaluable a mi formación personal y académica.

Mirco Cuellar

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El presente estudio y su publicación fueron viables gracias al respaldo de la Facultad de Ingeniería de la Universidad Peruana de Ciencias Aplicadas (UPC). Agradecemos la exigencia de la universidad en el fomento de la investigación académica entre los estudiantes de esta prestigiosa universidad y las futuras generaciones, pero que al mismo tiempo nos ha permitido obtener el ansiado título. Además, agradecemos sinceramente a la empresa de estudio por brindarnos su apoyo y colaboración durante el desarrollo de nuestra investigación. Su apertura, disposición y valiosa información fueron fundamentales para la realización de este trabajo.

Resumen

El presente estudio se basa en la investigación, realizada por los autores, denominada "Business Process Model Re-Design with a Data-Based Green Lean Management Approach with OEEM: A Case of Plastic Product Manufacturing" (Calderon et al., 2025), que constó de lo siguiente:

Propósito: Este estudio aborda la creciente necesidad de prácticas sostenibles en la industria manufacturera, impulsada por una mayor conciencia sobre los impactos ambientales y la presión regulatoria para reducir emisiones. Explora la aplicación del Método de Eficiencia General de los Equipos (OEEM) dentro del marco de la Gestión Lean Verde, enfatizando un enfoque basado en datos para la optimización sostenible de los procesos empresariales. A pesar del creciente interés en el OEEM, la investigación sobre su implementación sigue siendo limitada, especialmente en lo que respecta a las barreras que dificultan su adopción.

Definición del Problema: Este estudio aborda la urgente necesidad de mejorar la eficiencia operativa en los procesos de moldeo por inyección dentro de la industria de productos plásticos. El problema identificado se centra en los prolongados tiempos de configuración y las fallas en la maquinaria, lo que afecta negativamente la Eficiencia General de los Equipos (OEE) de las máquinas de moldeo por inyección. Estos desafíos impactan significativamente la productividad y el rendimiento.

Metodología/Resultados: Utilizando un enfoque sistemático, la investigación examina la relevancia de herramientas Lean Manufacturing, incluyendo 5S, TPM, SMED y estandarización, para resolver estos problemas. Se emplean metodologías como entrevistas, recopilación de datos e implementaciones experimentales. Diversas herramientas de Lean Manufacting se aplican estratégicamente para agilizar los procesos, optimizar el espacio de trabajo y mejorar la disponibilidad y el rendimiento de la máquina de moldeo por inyección. Los hallazgos clave revelan un aumento sustancial en la efectividad de la máquina, con mejoras en la disponibilidad del 7.72% y en el rendimiento del 7.51%. Destacablemente, el estudio resalta la exitosa aplicación de la metodología 5S, que sienta las bases para el mantenimiento autónomo, el mantenimiento preventivo y el SMED. El análisis y la

reducción de los tiempos de configuración contribuyen a una disminución significativa de 248 minutos a 117.5 minutos, confirmando la efectividad de las herramientas Lean en el logro de los objetivos establecidos.

Implicaciones Gerenciales: Este estudio ofrece a académicos, gerentes y tomadores de decisiones información valiosa sobre la aplicación práctica de las herramientas de Lean Manufacturing, proporcionando una perspectiva realista sobre cómo lograr mejoras sustanciales en los indicadores clave de desempeño. Se enfatiza un análisis equilibrado, evitando exageraciones y resaltando el valor práctico de los resultados. Además, establece la base para futuras investigaciones sobre los impactos sostenidos y la integración de Lean Manufacturing con tecnologías emergentes. Los hallazgos contribuyen al debate en curso sobre la eficiencia operativa en la manufactura, ofreciendo estrategias accionables para su mejora.

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Palabras clave: Analítica de Datos Empresariales, Modelo de Procesos de Negocio Verde, Gestión Lean, Método de Efectividad Global de los Equipos (OEEM), Sostenibilidad.

Abstract

The present study is based on the research conducted by the authors entitled “Business Process Model Re-Design with a Data-Based Green Lean Management Approach with OEEM: A Case of Plastic Product Manufacturing Firm” (Calderon et al., 2025), which consisted of the following:

Purpose: 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.

Problem Definition: This study addresses the pressing need to enhance operational efficiency in injection moulding processes within the plastic products industry. The identified problem centers on prolonged setup times and machinery breakdowns, hindering the Overall Equipment Effectiveness (OEE) of injection moulding machines. These challenges significantly impact productivity and performance.

Methodology/Results: Utilizing a systematic approach, the research investigates the relevance of Lean Manufacturing tools, including 5S, TPM, SMED, and standardization, in resolving these issues. Methodologies such as interviews, data collection, and experimental implementations are employed. Various Lean Manufacturing tools are strategically applied to streamline processes, optimize the workspace, and improve the availability and performance parameters of the injection moulding machine. Key findings reveal a substantial increase in machine effectiveness, with improvements in availability by 7.72 and performance by 7.51. Notably, the study underscores the successful application of the 5S methodology, forming the basis for autonomous maintenance, preventive maintenance, and SMED. The analysis and reduction of setup times contribute to a significant decrease from 248 minutes to 117.5 minutes, affirming the effectiveness of Lean Manufacturing tools in achieving predetermined goals.

Managerial Implications: This paper offers academics, managers, and decision-makers valuable insights into the practical application of Lean Manufacturing tools, providing a real-world perspective on achieving substantial improvements in key performance indicators. The study emphasizes a balanced analysis, avoiding exaggeration, and underscores the practical value of the results. It lays the foundation for future research to explore sustained impacts and the integration of Lean Manufacturing with emerging technologies. The findings contribute to the ongoing discourse on operational efficiency in manufacturing, offering actionable strategies for improvement.

This research was originally published in Calderon, J., Cuellar, M., Yildiz, O., Aranda, D., & Alvarez, J. C. (2025). Business Process Model Re-Design with A Data-Based Green Lean Management Approach with OEEM: A Case of Plastic Product Manufacturing Firm. *International Journal of Engineering Trends and Technology*, *73*(3), 289–314. https://doi.org/10.14445/22315381/IJETT-V73I3P122

Keywords: Business Data Analytics; Green Business Process Model; Lean Management; Overall Equipment Effectiveness Method (OEEM); Sustainability.

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1. ARTICULO EXTENDIDO (JOURNAL PAPER)

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

1.1 Introduction

The surge in global plastic production over the past few decades has marked a significant increase in materials consumption, exceeding the output of any other material in the last 150 years (WWF, 2022) . Although there was a slight decline in 2020 due to the pandemic, plastic production is projected to reach 619 million tons by 2030 (Dokl et al., 2024) . In 2023, this growth is estimated to exceed 413.8 million tons. Predominantly led by Asian countries, particularly China, which accounts for 33.3 percent of the global total (Plastics Europe, 2024), and the plastic industry faces critical environmental challenges, with 57 percent of the waste finding its way into natural environments such as rivers and landfills, posing severe threats to the ecosystem (León & Casas, 2024).

Environmental concerns have increased, prompting organizations like the World Economic Forum to propose a drastic reduction in plastic production to mitigate environmental emissions(Dokl et al., 2024). Balancing the environmental impact with the economic significance of the plastic industry, which represents a significant source of employment, presents a challenge for policymakers and industry stakeholders (Plastics Europe, 2024). The injection molding process, utilized by over 90 percent of plastic industries globally, stands at the core of plastic manufacturing(Quiroz & Vega, 2022). For companies operating in this sector, optimizing the injection molding machine's performance becomes a key factor for improving overall operational efficiency (Jaqin et al., 2020). However, many companies encounter challenges, such as frequent machine stoppages and extended setup times, contributing 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 presents 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 (Calderon et al., 2023).

This research focuses on a specific company within the plastic manufacturing sector grappling with inefficiencies in its molding process. The main operational issues are associated with frequent stoppages due to prolonged setup times (57.6 percent) and injection molding machine failures (41.1 percent). Overall Equipment Effectiveness (OEE) is used as the performance indicator, showing 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 (Adithya & Anantharaj, 2021). In contrast to the plastics sector benchmark, the company faces a significant research gap of 15.2 percent, indicating the need for improvement by applying Green Lean Manufacturing tools. Therefore, the main problem identified is the low effectiveness of the injection molding machine (53.1 percent). Almashaqbeh and Munive Hernandez 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) (Almashaqbeh & Hernandez, 2024). 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. applied Lean Manufacturing, including 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 (Makwana et al., 2023).

The need to adress these efficiency challenges is related by the immediate impact on the company’s viability, environmental responsibilities, and the overarching sustainability of the plastic manufacturing industry. Inaction not only affects the operational performance of the company, but also perpetuates environmental harm and limits opportunities. As such, this research is a theoretical exploration and a crucial step towards rectifying an urgent problem with far-reaching consequences.

This research contributes to the analysis of efficiency improvement in injection molding processes through the practical application of Lean Manufacturing principles, specifically 5S, TPM, and SMED. Based on 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 and contributes to the academic discourse on integrating Lean Manufacturing in the plastic manufacturing sector. 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. In an environment marked by growing environmental concerns, both environmental and operational performance issues must be addressed as a combined optimization problem. However, Lean tools, while effective in improving operational efficiency, often overlook the environmental impact generated by these processes (Braglia et al., 2025). 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 underscoresthat 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 provides a review of 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, and the scenario. In Section 5, the results are presented 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.

1.2 Literature Review

Lean Manufacturing is a project management methodology aimed at delivering value to customers by improving productivity through systematic elimination of waste (Rose et al., 2019). This methodology originated in the Toyota company in the 1950s when there was a need for the production of small cars at a low cost. 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 (Jaqin et al., 2020). Additionally, the corporate culture emphasizes innovation, where employees can identify and solve problems (Berggren, 1993).

Traditional Lean approaches mainly focus on improving operational efficiency; however, they often overlook the environmental impacts generated throughout production processes, such as high energy consumption, increased carbon emissions, and excessive material waste. In response to this limitation, Green Lean Manufacturing emerges as an approach that integrates Lean principles with sustainability objectives (Braglia et al., 2025).

The literature indicates that while many authors promote Lean tools to enhance operational performance, only a limited number address the importance of incorporating sustainability considerations into the optimization of critical processes. Furthermore, despite the well-documented benefits of Lean Manufacturing in improving efficiency, there remains a notable gap in operational frameworks that jointly address both performance and environmental concerns. This gap highlights

the need for methodologies that also focus on reducing resource consumption and environmental impact, ensuring efficient and sustainable production processes (Queiroz et al., 2024).

Among the principles associated with 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 (Quiroz & Vega, 2022). Another important point is pulling processes, which aim to reduce excess inventory and improve production flexibility while meeting demand requirements accurately. Long-term relationships with suppliers and the end customer are also emphasized, seeking to provide a solution to their needs (Klabusayová, 2014). 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 (Shakoor et al., 2019).

Several studies report that organizations may achieve cost reductions of up to 50% after implementing this methodology (Xiang & Feng, 2021). Among the benefits of this methodology, known as Lean Production, are 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 (Xiang & Feng, 2021). 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 (Haddad et al., 2021).

1.2.1 5S Methodology

The 5S methodology originated in Japan based on five principles, each represented by the letter "S." Each principle represents a stage in the process and is complemented by continuous improvement, known as Kaizen (Kumar et al., 2018). 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. The 5S methodology is widely applied in organizations with multiple operational processes (Makwana & Patange, 2022).

Various authors highlight the effectiveness of 5S in workforce training, as its objective is to standardize work, facilitate the visualization of deviations in the process, and facilitate their respective elimination (Shahriar et al., 2022).

That's why, the methodology has been applied to address different operational problems in manufacturing environments. One example is the improvement of productivity in a plastic manufacturing company that faced issues with long material search times, causing delays in the assembly area. To solve this problem, the total participation of the workers was required over a period of seven months. The results showed a reduction of 5 hours per month in material search time and an increase in productivity from 75% to 100% (Makwana & Patange, 2022).

On the other hand, another company in the same industry had issues with waste that were affecting 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 (Shahriar et al., 2022).

Similarly, a small-scale manufacturing industry with an initial productivity level of 60% implemented 5S to improve workplace conditions and employee engagement. Whitin the first year of implementation, productivity increased by 55%, resulting in a significant improvement in overall performance (Senthil Kumar et al., 2022).

1.2.2 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 (Haddad et al., 2021; Quiroz & Vega, 2022). This philosophy focuses on participation across organizational levels to support long-term equipment reliability and consistent operational performance (Ribeiro et al., 2019).

In various studies, Overall Equipment Effectiveness (OEE) is identified as the primary indicator for measuring performance after implementing this lean tool (Abidin et al., 2022). Furthermore, it is composed of the three components: 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 (Adithya & Anantharaj, 2021).

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. To address this issue, a planned maintenance proposal was implemented for the two malfunctioning machines. The results showed an efficiency increase of 11.43% and 9.2% for both equipment respectively after implementing TPM (Adithya & Anantharaj, 2021).

Another study conducted in Malaysia identified operational problems related to reprocessed products, production bottlenecks, and delivery delays. Autonomous maintenance and continuous improvement practices were implemented, and three key indicators were used to monitor 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% (Abidin et al., 2022)

Additionally, a case study in a PVC pipe manufacturing company applied TPM with a continuous improvement approach to reduce customer dissatisfaction resulting from product nonconformities. The problem revolved around customer dissatisfaction due to products not meeting the given specifications. The OEE indicator was used to measure 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 the implementation of 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 (Nallusamy et al., 2018).

1.2.3 Single-Minute Exchange of Die (SMED)

Single-Minute Exchange of Die (SMED) is a technique considered to reduce setup times in a production line. In general, the goal is to decrease it to a single digit, that is, less than 10 minutes (Lozano et al., 2019). That's why it is widely recognized one of the lean manufacturing tools because it helps companies achieve significant cost savings (Haddad et al., 2021). This method originated from the need to reduce batch size in a Japanese company and was implemented by Shigeo Shingo (Oliveira & Borges, 2019)

To implement this methodology, a series of concepts were defined, such as the

changeover time from manufacturing one product to the next, which is when the equipment is inactive. Another concept is the operation preparation, which is considered a non-value-added activity (Lamani et al., 2020). 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 applied the use of this method to generate expected results in 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. To address this issue, two phases were proposed for implementing the technique. 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 (Oliveira & Borges, 2019).

In another study, Parwani analyzed the issue of unproductive times due to the change of plastic parts in a rotary thermoforming machine was identified. In the current situation, the company loses 165 minutes per day across three shifts. By implementing a structured SMED approach setup time was reduced to 9 minutes per shift, while programming were decreased by 6% (Parwani & Hu, 2021).

1.3 Theoretical Background

1.3.1 Lean Manufacturing Applied to Production Processes

In this section, we will thoroughly examine the evolution, fundamental principles, and applications of Lean Manufacturing. In this research, it is considered ass a process-level improvement approach, focused on enhancing operational efficiency within production processes rather than an enterprise-wide management system.

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 (Womack et al., 1990) . 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 (Jaqin et al., 2020). 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 (Berggren, 1993).Therefore, integrating processes generates huge opportunities to improve costs, quality, and response times in different organizations (Silver, 2004). 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 the implementation, challenges, and outcomes of lean methodologies 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 (Sartal et al., 2022). They have argued that the 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. Thereby, 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 (Quiroz & Vega, 2022). 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 (Klabusayová, 2014). These principles significantly impact all facets of production and service organizations,

substantially enhancing their efficiency and effectiveness (Shakoor et al., 2019). Prajogo, Mena, and Nair examine the fit between supply chain strategies and practices using a contingency model (Prajogo et al., 2018). 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 (Hopp & Spearman, 2004). 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 (Brown et al., 2015). 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 (Hopp & Spearman, 2004). 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. have 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 (Brown et al., 2015). 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 of regressing from the lean philosophy. Another challenge faced by lean initiatives is the lean islands problem, where lean practices remain within the organizational boundaries (Hopp & Spearman, 2004). Azevedo et al., have proposed a theoretical framework to analyze the effect of green and lean upstream supply chain practices on business sustainability (Azevedo et al., 2012). 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 (Colombari & Neirotti, 2024). Their multilevel study shows that high-involvement lean practices and skilled frontline managers enhance the adoption of DDM. This integration of 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 (Galankashi et al., 2022). Their model optimizes cost, lead time, waste minimization, and product quality across multiple case studies. The integration of 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 (Krishnan et al., 2021). 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 develop a sustainable production value measurement model integrating lean and six sigma within the Industry 4.0 context (Ganjavi & Fazlollahtabar, 2023). 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 (Demirkesen & Bayhan, 2022). 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 (Monserrat et al., 2024). 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 outcomes for learners. Sum et al., analyzes the implementation of lean principles in a shared service center (SSC) context (Sum et al., 2020). 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 (Middleton & Joyce, 2012). 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.
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Research indicates that companies can achieve substantial cost reductions, up to 50 percent, by adopting lean manufacturing methodologies (Xiang & Feng, 2021). 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 (Xiang & Feng, 2021). 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 (Haddad et al., 2021). 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 (Atasu et al., 2020). 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, 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 the Table 1 based on the insight of Ruben et al., and Garza-Reyes (Ben Ruben et al., 2020; Garza-Reyes, 2015). This comparison elucidates each methodology's focus, impact on competitiveness and profitability, approaches to waste reduction and customer orientation.

Firstly, considering the focus, Lean Production is an approach aimed at enhancing industrial performance by minimizing waste. This methodology systematically identifies and removes activities that do not contribute value to

the product, thereby optimizing operations and increasing efficiency. In contrast, Green Technology focuses on improving ecological efficiency by increasing energy utilization efficiency. This involves adopting environmentally sustainable practices and reducing the ecological footprint of production processes. Six Sigma, on the other hand, 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. In terms of 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 not only appeals to environmentally conscious consumers but also involves complying with regulatory requirements, potentially reducing compliance costs. Six Sigma increases competitiveness by delivering high-quality products and reducing the need for rework. By focusing on quality improvement, it enhances customer satisfaction and reduces costs associated with quality failures, thereby strengthening the firm's market position.

Table 1

Comparison between Lean Production, Green Technology, and Six Sigma

	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.

Note. The table presents a comparison of Lean Production, Green Technology, and Six Sigma based on the literature reviewed.

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; this ensures that 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 through the reduction of 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 found application 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 (Banawi & Bilec, 2014).

1.3.2 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:

Several studies have examined the relationship between lean design of production systems and sustainability, highlighting its contribution to environmental, economic and operational performance. Other research focuses on the integration of lean production with quality and management approaches, like Sig sixma, Green Lean, and Total Quantity Management, emphasizing their combined impact on operational perfomance. Additionally, Lean production has been studied in relation to economic sustainability and long-term competitiveness. Cultural transformation has also been recognized as a key factor in lean implementation, as it affects employee engagement and the effective adoption of lean practices. Lean production in conjunction with other operational improvement approaches, demonstrating its applicability whitin manufacturing and production process.

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 (Chen et al., 2020). 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., conduct an extensive literature review on the integration of lean design, Six Sigma, and sustainability (Cherrafi et al., 2016). 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 (García-Alcaraz et al., 2022). Important findings regarding the role of lean manufacturing tools in sustainability are presented, using the example of Mexican maquiladoras. Helleno et al., undertake a study on the integration of sustainability indicators into the lean design of production systems in Brazil (Helleno et al., 2017). The study identifies economic, social, and environmental factors, presenting novel sustainability indicators relevant to the manufacturing process. Jamwal et al., conduct a long-term (twelve years) observational study on the evaluation of sustainability trends in the manufacturing sector alongside lean design of production systems (Jamwal et al., 2022). 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 (Jum'a et al., 2023). 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, the studies within 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 (Kaswan et al., 2023). 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 within this theme, involving a systematic literature review focusing on the impact of supply chain sustainability in manufacturing SMEs (Kosasih et al., 2023). 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 (Longoni & Cagliano, 2015). 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 for the integration of lean, sustainability, and quality management system (QMS)(Manmohan & Shalij, 2022). The study demonstrates the effectiveness of the approach in predicting manufacturing parameters optimally using artificial neural networks and the imperialist competitive algorithm. Milosevic et al., conduct a case study on the application of the PDCA cycle through lean manufacturing to achieve sustainability (Milosevic et al., 2015) The findings suggest that the implementation of lean tools, 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 (Misopoulos et al., 2018). 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 integration of 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. 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 (Piyathanavong et al., 2019). Psarommatis et al., advocate the Zero-Defect Manufacturing (ZDM) method for higher manufacturing sustainability (Psarommatis

et al., 2022). 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 (Ramos et al., 2018). 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 (Tong & Huaccho Huatuco, 2019). 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(Tran et al., 2024). 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 (Agrawal et al., 2019). 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 aligned to the circular economy. Agrawal and Ülkü have focused on modular upgradability as a green design strategy (Agrawal & Sezer, 2018). 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 carried out a study that focuses on optimizing waste-to-energy operations (Ata et al., 2012). 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 (Atasu et al., 2020). 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 (Betcheva et al., 2021). 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 (Corbett, 2024). 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 (Corbett & Klassen, 2006). 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 (de Zegher et al., 2019). 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. By determining optimal contract structures and identifying the role of supply channels, the study offers valuable insights into strengthening responsible supply strategies. Dong et al. have investigated the effects of mobile money services

on the value chain, particularly in emerging economies (Dong et al., 2019). 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 (Drake & Spinler, 2013). 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 (Hopp & Spearman, 2004). 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 (Hu et al., 2015).

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 (Jira & Toffel, 2013). 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 (Krishnan et al., 1999). The research delves into the challenges and benefits of developing families of technology-based products. Targeting a market where customers make choices based on product performance, the study emphasizes the importance of using a common product platform to reduce individual product development costs. Additionally, a model is proposed to capture product development costs based on different variants

of a family. 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.

The traditional Lean approach focuses on improving operational efficiency, but it overlooks the environmental impacts generated in different processes, such as high energy consumption, higher carbon emissions, and increased material waste. That is why, Green Lean emerges as an approach that integrates Lean principles with sustainability goals. (Braglia et al., 2025). The literature indicates that while many authors promote Lean tools to enhance operational performance, only a limited number address the importance of incorporating sustainability considerations into the optimization of critical processes (Dieste et al., 2020).

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 with a focus 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 the adoption of this sustainability-based approach are mainly resistance to change, technical challenges in integrating the tools, and the impact on organizational culture. Additionally, sustainable practices have an impact on 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 as well. 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.

1.4 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 (Kumar et al., 2018). In the short term, this methodology enhances process efficiency with expected outcomes, rendering it a viable system for companies with multiple processes (Makwana & Patange, 2022).

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 (Shahriar et al., 2022). 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 (Makwana & Patange, 2022). 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 (Shahriar et al., 2022). 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 (Senthil Kumar et al., 2022).

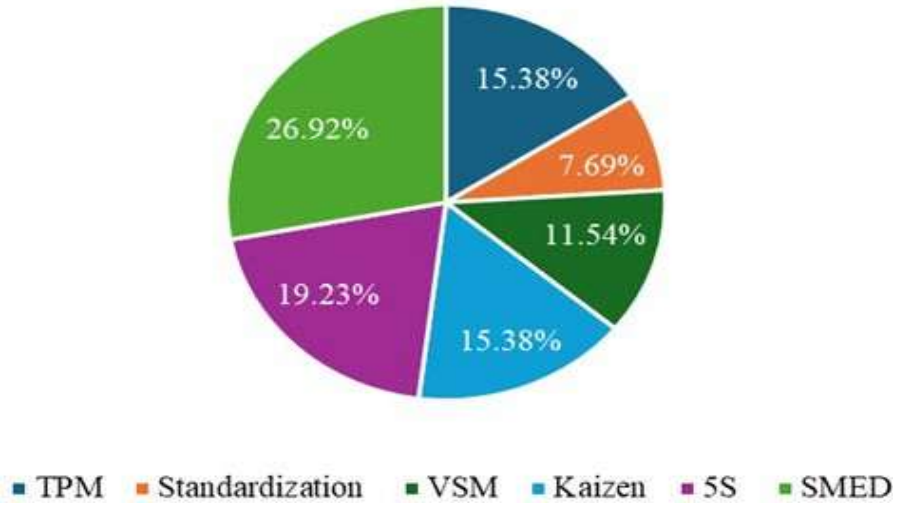
Total Productive Maintenance (TPM) is a continuous improvement system originating from Japan, designed to significantly increase production in a company while boosting employee motivation (Haddad et al., 2021; Quiroz-Flores & Vega-Alvites, 2022). This philosophy involves engaging human capital at all levels for

sustained operational effectiveness (Ribeiro et al., 2019). In numerous studies, Overall Equipment Effectiveness (OEE) is a critical metric for evaluating performance after implementing this lean tool (Abidin et al., 2022). 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 (Adithya & Anantharaj, 2021). 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 (Adithya & Anantharaj, 2021). 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 (Nallusamy et al., 2018). 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 (Nallusamy et al., 2018). 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 (Haddad et al., 2021). The aim is to minimize setup times to a single digit, ideally less than 10 minutes (Lozano et al., 2019). Originating from the need to reduce batch size in a

Japanese company, it was implemented (Oliveira & Borges, 2019). The method includes crucial concepts like changeover time from one product to another during equipment downtime. Another critical concept is operation preparation, identified as a non-value-added activity (Lamani et al., 2020). 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.

Figure 1

Weighting based on researched tools



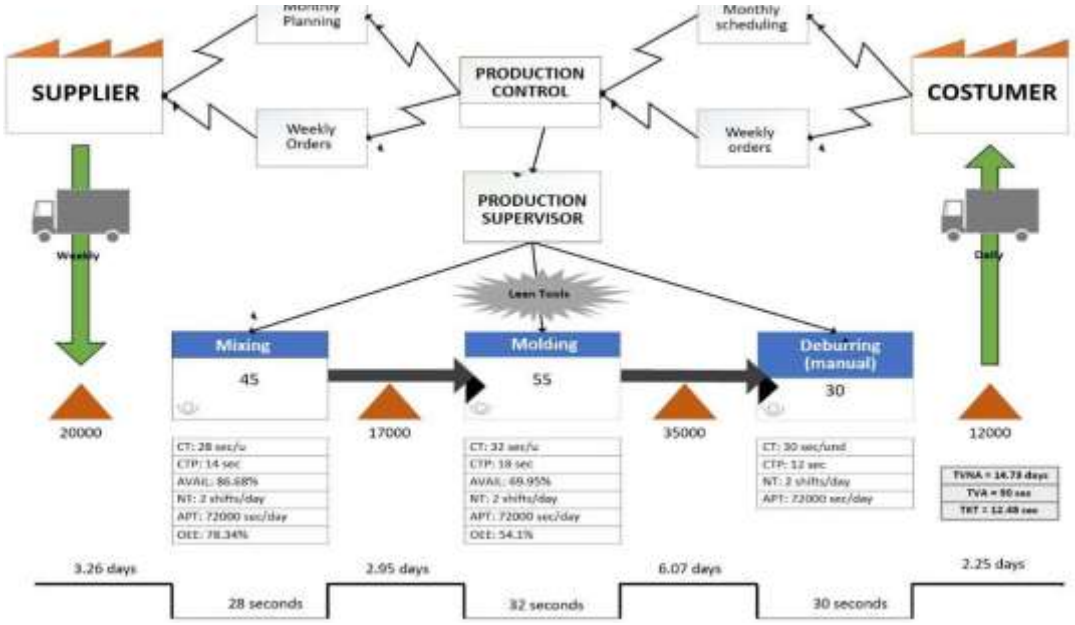
Note. The percentages represent the frequency of use of the identified tools in the reviewed studies.

Additionally, the initiative saved 180m^2 of space within the plant(Oliveira & Borges, 2019). 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 (Parwani & Hu, 2021). 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(Quiroz & Vega, 2022). After reviewing multiple studies, weight was assigned to the most frequently utilized lean tools.

As shown below, 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 adjustment. Figure 2 presents a production system model based on Value Stream Mapping focusing on process interaction and overall system performance. This representation emphasizes the coordination of all processes and the functioning of the production system as a whole.

Figure 2
Production system model based on the current VSM



Note. Current-state Value Stream Map (VSM) showing the flow of materials and

information throughout the production process. Author's own elaboration based on data collected from the company.

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 (Quiroz & Vega, 2022). 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.

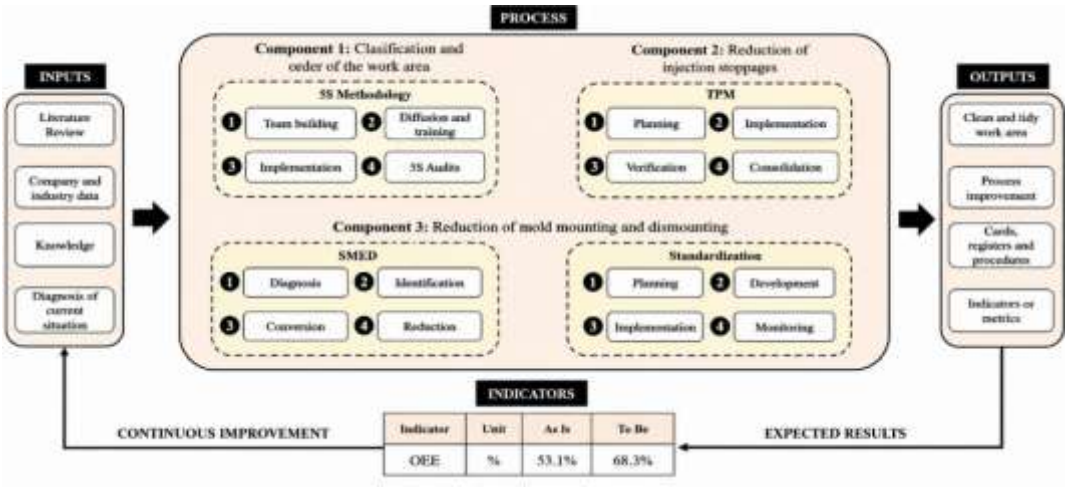
The input and output indicators specified in the model play a critical role in monitoring and evaluating the effectiveness of the applied tools. Metrics such as reduced downtime and increased production output are tangible indicators of the model's success. The authors' careful definition of anticipated 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) (Mahmoud et al., 2019). 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 (Mahmoud et al., 2019).

To illustrate the practical implications of Mahmoud's study, let's consider a manufacturing scenario with various machines of different capacities. Before the introduction of the OECL concept, evaluating the overall effectiveness and cost implications of these machines 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, but in an evaluation

incorporating OECL and integrating operating costs, it may not be the most cost-effective option. 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.

Figure 3
Proposed model



Note. Proposed improvement model integrating 5S, TPM, SMED, and Standardization methodologies to improve operational performance and Overall Equipment Effectiveness (OEE).

It shelds 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 serves as 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 noticeable 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.

1.4.1 Process Improvement of Injection Molding Operations

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

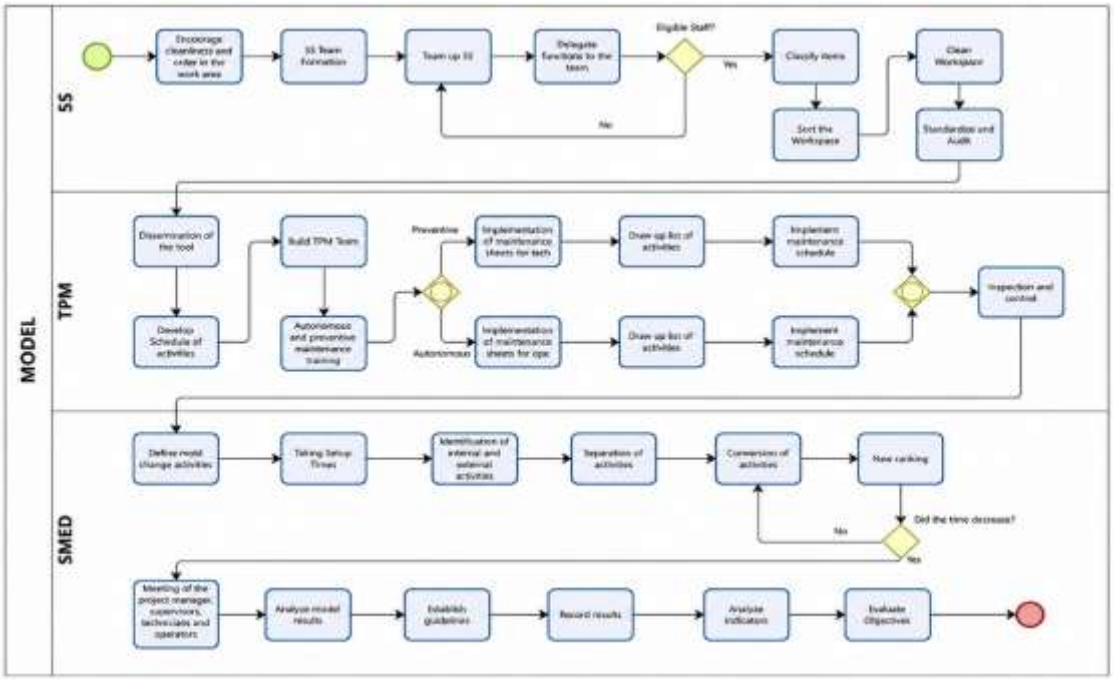
implemented at each step to standardize processes and identify potential improvements based on continuous improvement. Following these stages, audits are conducted to assess the impact of these tools and compare the results with the project's initial state. In summary, the 5S methodology instils discipline 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, with technicians and operators playing 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. 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.

Figure 4
Detailed model



Note. Implementation model integrating the 5S, Total Productive Maintenance (TPM) and Single- Minute Exchange of Die (SMED) methodologies to improve workplace organization, equipment maintenance, and setup time reduction.

1.4.2 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.

Table 2
The scenario's technical gap

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

Note. The table presents the technical gap between the company under study and its industry.

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. An 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 the injection molding. The results indicate a notable improvement in effectiveness, surpassing the initial 53.1 percent level.

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, economical and sustainability outcomes. The subsequent section presents findings from the three different lean management analysis methods, each enhancing efficiency in the examined manufacturing company.

1.4.3 Detailed model

In figure 3, the improvement proposal 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.

1.4.3.1 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 training will be provided by an expert in the field. 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, the promotion of order is emphasized 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.

Figure 5
Concepts of 5S implementation



Note. The figure ilustrates the five stages of the 5S methodology and their corresponding objectives for workplace organization and cleanliness.

1.4.3.2 Autonomous and Preventive Maintenance

As the second component, the Total Productive Maintenance tool is implemented, which, similar to the previous one, is divided into four phases. It begins with the planning and dissemination of the tool in the work area. In this phase, a TPM team is formed, led by the maintenance manager. The main resources are technicians and operators, as they play an essential role 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 the pillars of autonomous and preventive maintenance. 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 the completion of assigned tasks in their respective areas.

Documentation is used to record the implementation progress for better control.

As the final phase, the entire team is evaluated through maintenance audits. TheMean 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.

Figure 6
Phases for TPM implementation

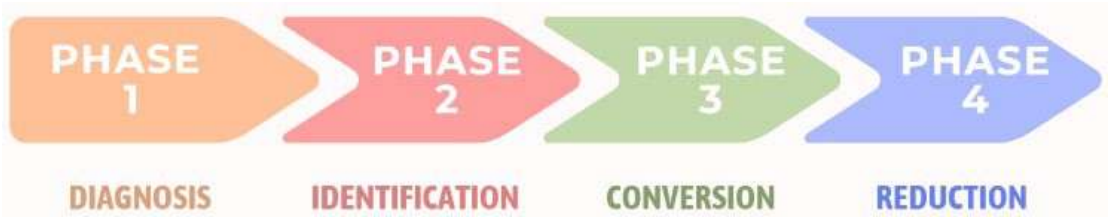


Note. The figure presents the four phases of the Total Productive Maintenance (TPM) methodology, including planning, implementation, checking, and consolidation, for the systematic execution of maintenance activities.

1.4.3.3 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 through the introduction of 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 review of the literature and the current situation of the company.

Figure 7
Phases of SMED implementation



Note. The figure presents the sequential phases of the Single-Minute Exchange of Die (SMED) methodology, comprising diagnosis, identification, conversion, and reduction to improve setup operations.

1.5 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.

1.5.1 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 (Oliveira & Borges, 2019). The sequential application of each Lean tool is meticulously executed in adherence to their respective stages, ensuring favorable outcomes (Haddad et al., 2021). 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 (Zahraee et al., 2020).

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 3.

Table 3

Description of Random Variables

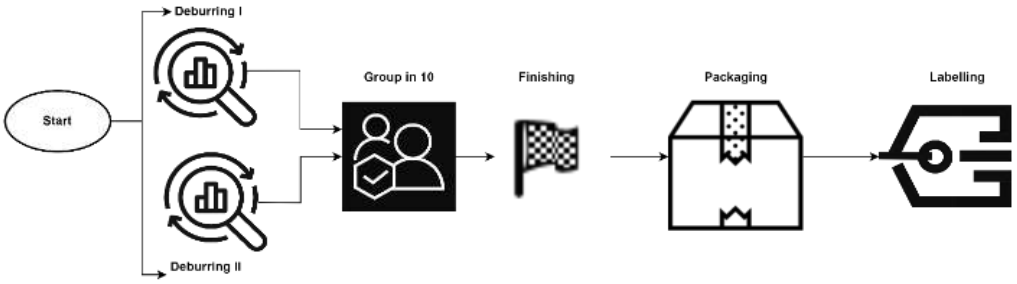
Variables	Description
TBA	Time between arrivals
OT MIX I	Operating time mixer I
OT MIX II	Operating time mixer II
OT INJ I	Operating time injector I
OT INJ II	Operating time injector II
OT DEB I	Operating service time deburring I
OT DEB II	Operating service time deburring II
OT FIN	Operating service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

Note. The variables presented correspond to the random input variables used to develop the discrete-event simulation model in Arena Simulation Software.

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.

Figure 8

Grouping in batches of 10 after the deburring process



Note. The following figure shows the graphical representation of the system after the deburring process up to the labeling process.

1.5.2 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. 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.

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

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

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

$$OEE(\%) = Availability \times Performance \times Quality \qquad (4)$$

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.

Table 4
Current situation of operation results

	Count	**Average**
Results of the Current Situation	Average time of a piece in the injection molding 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%**

Note. The table presents the validation of the current situation of the simulation. Own elaboration based on the results obtained from the simulation in Arena Software.

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.

1.5.3 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 OEE indicator improvement 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 concerning 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 all detailed information about the operation

performance in three scenarios in the Table 5. as seen below.

Table 5

Comparison between three different scenarios

Count	Pessimistic Scenario Average	Typical Scenario Average	Optimistic Scenario 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%**

Note. The table presents a comparison of the results obtained under three different scenarios. Own elaboration based on the results obtained from the simulation in Arena Software.

1.6 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 molds' 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 (Quiroz & Vega, 2022). 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 (Haddad et al., 2021)

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%**

Note. The table presents the improvements achieved in each of the SMED phases.

The service level, a metric gauging production or operational capacity concerning customer demands within a specified period, currently stands at 72.82 percent as we can show 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 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%

Note. The table presents the improvements achieved in the service level for each scenario.

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 (Adithya & Anantharaj, 2021) 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 (Makwana & Patange, 2022).

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.

1.7 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.

6.1. Practical Implications

In this study, relevant data for the reconstruction of 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:

-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.

-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.

-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 the reduction of setup times in plastic product manufacturing and extruder machine setups, highlight the importance of workplace organization and acquiring necessary tools for task execution. Focusing on these root causes can lead to continuous operational improvements.

-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.

-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 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.

6.2. Limitations and future research

This research, with its specific focus on a single-case study and a limited time frame, 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. To guide researchers in future endeavors, recommendations regarding research design, sample selection, and alternative research focuses are outlined.

For future research design, adopting a longitudinal methodology covering an extended period is proposed. 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 facilitating 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 focus on exploring and confirming 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.

2. Conclusiones de la tesis

En conclusión, a lo largo de esta investigación se ha plasmado las problemáticas presentes en el sector de plásticos, tanto a nivel nacional como global. Se ha evidenciado que el desempeño de este sector está marcado por una combinación de crecimiento y presiones regulatorias, lo que limitaría la evolución de este sector orientado cada vez más a una economía circular. Una vez finalizado el desarrollo de esta investigación, se presentan las conclusiones en función a los objetivos establecidos:

- Luego de un análisis exhaustivo del proceso productivo, se determinó que el proceso de moldeo por inyección es el más crítico. En dicho proceso, se observó los constantes problemas en la máquina inyectora, el cual contaba con una baja eficiencia operativa (OEE) de 53.1%, causado principalmente por las paradas por averías y los excesivos tiempos de setup de la inyectora. Por ende, ello afecta a los parámetros claves del OEE, dentro de los cuales se tuvo una disponibilidad de 68.47% y un rendimiento de 82.04%, siendo los más críticos.
- Una vez encontrados los parámetros críticos, se procedió a realizar cambios sustanciales a través de la aplicación de Lean Manufacturing. Por consiguiente, se incrementó la disponibilidad del 68.47% hasta 77.68%, lo que representa un aumento en el tiempo real de funcionamiento que asciende a 6,627 minutos o 110.45 hrs, y una mayor producción con un incremento de 13,172 piezas.
- El parámetro de rendimiento sufre una variación significativa, ya que, manifiesta un incremento de 4.65%. Dicho valor representa el funcionamiento de la inyectora respecto a su capacidad total, es decir, la máquina en un escenario futuro funcionará al 86.69% respecto a su capacidad total, lo que contribuye a la mejora la producción.
- El tiempo de montado y desmontado de moldes incide en el 37.8% del total de causas que originan la baja disponibilidad de la inyectora. En términos cuantitativos este proceso tarda 248 minutos, y con la aplicación del SMED tanto en sus fases de diagnóstico, identificación, conversión y reducción, se pudo disminuir este tiempo en 52.62%.

- Por otra parte, el nivel de servicio actual es de 72.82%, no obstante, con la propuesta de solución se logra un aumento de 11.24%. Es decir, se logró una mayor producción de piezas plásticas y una reducción del tiempo de setup, asimismo, permitió atender más ordenes de producción y cumplir con las fechas de entrega.
- La eficacia de las herramientas Lean tales como la metodología 5S, TPM, SMED y Estandarización queda demostrada dado que mitiga problemas frecuentes en la industria de plástico. Asimismo, se observó las mejoras potenciales que se pueden alcanzar con la aplicación estratégica de cada una de estas herramientas.
- Luego de analizar el proceso de producción, se encontró que el problema principal está en el moldeado por inyección. Con un valor actual de 53.1% en el OEE consecuencia de fallos mecánicos, eléctricos y altos tiempos de paradas. Esto representa el 19% de su facturación anual actual y aplicar esta propuesta se espera un aumento en el tiempo de funcionamiento a 1478 horas al mes.
- Luego de implementar la propuesta de mejora en base al mantenimiento productivo total con respecto a los pilares de prevención y autonomía, se concluye que se genera una disminución considerable en la cantidad de averías y el tiempo promedio de reparación de cada uno. Para ello, se analizó los indicadores de MTTR y MTBF para medir estos aspectos. En la situación actual, el intervalo de tiempo en producirse una avería es de18.89 horas el cual después de la implementación aumenta a 24 horas durante el horario laboral. Adicional a esto, el tiempo de reparación por fallo pasó de 3.02 a 2 horas en promedio. Es decir, hubo un incremento del 27.05% y una reducción del 33.77% con respecto a nuestros indicadores.
- En futuras investigaciones, resultará fundamental explorar y confirmar la aplicabilidad de las Metodologías Lean en contextos industriales similares y más amplios a fin de reflejar con precisión el impacto de dichas herramientas Lean el cual deben convertirse en una prioridad para las futuras investigaciones, por lo que pueden tomar la investigación desarrollada como base. De esta manera, se propondrían estrategias innovadoras y sobre todo se

perfeccionaría la metodología Lean Manufacturing para la mejora en el rendimiento operativo.

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ANEXOS

Anexo 1

1 Objetivo general

- El objetivo general es proponer un modelo basado en las herramientas 5S, TPM y SMED para incrementar la efectividad en el proceso de inyección en una empresa de productos plásticos.

2 Objetivos específicos

Los objetivos específicos son:

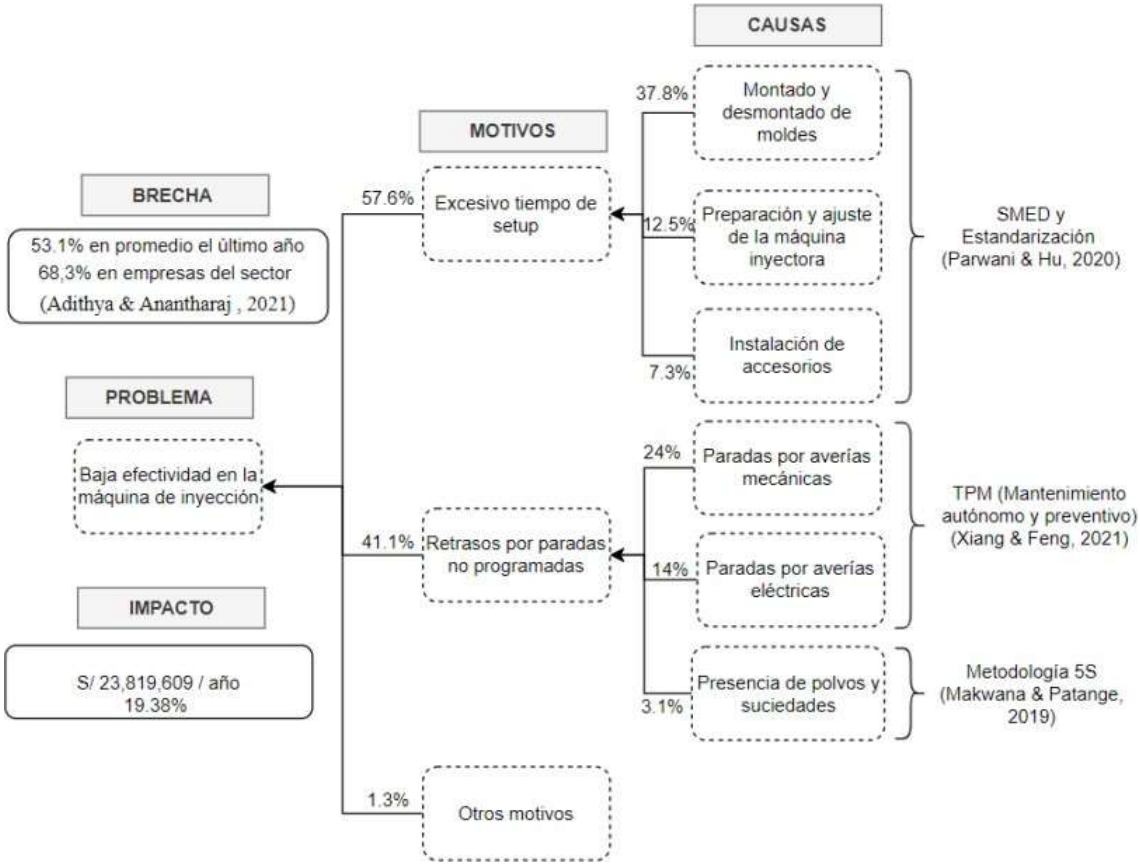
- Evaluar los parámetros críticos del OEE en el proceso de inyección en una empresa de productos plásticos.
- Disminuir el tiempo de paradas por averías en el proceso inyección en una empresa de plásticos.
- Reducir los tiempos de setup en el proceso de inyección en una empresa de plásticos.
- Incrementar el tiempo de funcionamiento del proceso productivo en una empresa de plástico.
- Incrementar el nivel de servicio en el proceso productivo en una empresa de plásticos.

2 Cronograma proyectado

ITEM	MES	AGOSTO				SETIEMBRE				OCTUBRE				NOVIEMBRE				DICIEMBRE				ENERO				FEBRERO				MARZO				ABRIL				MAYO				JUNIO				JULIO			
	SEMANA	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
PRELIMINAR																																														
Identificación de personal de trabajo	**S1-S2**																																													
Formación de grupos de trabajo	**S2-S4**																																												
Capacitación y difusión de las herramientas Lean	**S3-S4**																																												
FASE 1: Metodología 5S																																													
Comunicación y difusión de la metodología 5S	**S3-S4**																																												
Reunión entre el personal del área y elección de responsables	**S4-S5**																																												
Delegación de roles y responsabilidades	**S5**																																											
Reunión con los expertos 5S	**S5-S6**																																											
Capacitación en las fases Seiri, Seiton, Seiso, Seiketsu y Shitsuke	**S5-S6**																																												
Registro en fotografías de la situación actual	**S6**																																											
Preparación y adquisición de materiales	**S6**																																											
Clasificación del área de trabajo	**S6-S7**																																											
Organización y orden en el área de trabajo	**S7-S8**																																											
Limpieza del área de trabajo	**S8-S9**																																											
Evaluación del cumplimiento de objetivos	**S9**																																											
Evaluación de los impactos de las 5S	**S9**																																											
Estandarización de las 5S (Seiketsu y Shitsuke)	**S9-S10**																																											

FASE 2: Mantenimiento Productivo Total (TPM)	
Campaña de difusión del TPM	**S10-S11**
Formación y capacitación técnica a los jefes, supervisores y operarios	**S11-S13**
Diseño del plan de mantenimiento	**S13- S16**
Implementación del programa de mantenimiento autónomo	**S17-S21**
Elaboración de registros, procedimientos y fichas	**S22-S23**
Establecimiento de procesos de limpieza y mantenimiento mecánico	**S23-S24**
Implementación del programa de mantenimiento preventivo	**S25-S27**
Programación de actividades de mantenimiento de máquinas	**S27-S30**
Establecimiento de repuestos	**S31-S32**
Programación de actividades preventivas en el área de moldeo	**S32-S35**
Establecimiento de métricas de control	**S35**
Estandarización del TPM	**S35-S36**
FASE 3: Single Minute Exchange of Die (SMED)	
Formación del equipo SMED	**S37**
Comunicación y difusión del SMED	**S37-S38**
Diagnóstico de actividades y recolección de tiempos	**S38-S39**
Análisis de las actividades tanto internas como externas	**S40**
Análisis de resultados encontrados	**S40-S41**
Planteamiento de propuestas	**S42-S43**
Conversión y clasificación de actividades	**S44**
Análisis de tiempos obtenidos y comparación de resultados	**S44**
Definición de nueva secuencia de actividades	**S45-S46**
Recolección de nuevos tiempos	**S46**
Clasificación de nueva secuencia de actividades	**S46**
Comparación de resultados obtenidos	**S46-S47**
Evaluación del equipo SMED	**S47-S48**
Estandarización del SMED	**S48**

Árbol de problemas



Presupuesto del proyecto

PRESUPUESTO DEL PROYECTO				
Descripción	**Unidad**	**Cantidad**	**Monto**	**Total**
Fase de planificación				
Primera visita a la empresa (entrevista, autorización y selección del problema)	N°	1	S/ 50.00	S/ 50.00
Estudios sobre gestión de mantenimiento	Mes	1	S/ 250.00	S/ 250.00
Reunión con expertos para la implementación del TPM, SMED y 5S	N°	2	S/ 150.00	S/ 300.00
Primera investigación del Estado del Arte (Papers de pago Scopus)	Mes	4	S/ 25.00	S/ 100.00
Elaboración de la gestión del proyecto (Licencias Office y Ms Project)	Mes	2	S/ 90.00	S/ 180.00
Subtotal				S/ 880.00
Fase de investigación				
Segunda visita (entrevistas con miembros de la empresa)	N°	1	S/ 50.00	S/ 50.00
Elaboración del diagnóstico del proceso (transporte, almuerzo, materiales, etc)	Mes	3	S/ 120.00	S/ 360.00
Segunda investigación del Estado del Arte (Papers de pago Scopus)	Mes	2	S/ 25.00	S/ 50.00
Adquisición de materiales sobre metodologías Lean (libros)	Mes	4	S/ 82.00	S/ 328.00
Asesoría con expertos en el campo	N°	2	S/ 150.00	S/ 300.00
Subtotal				S/ 1,088.00
Fase de diagnóstico				
Tercera visita (levantamiento de datos)	N°	1	S/ 120.00	S/ 120.00
Adquisición de equipos electrónicos (laptops, impresoras, libretas, hojas, etc)	N°	1	S/ 2,250.00	S/ 2,250.00
Elaboración del diagnóstico del problema principal (transporte, almuerzo, materiales, etc)	Mes	2	S/ 150.00	S/ 300.00
Plan de contingencia	Mes	1	-S/ 300.00	-S/ 300.00
Subtotal				S/ 2,370.00
Fase de desarrollo del diseño				
Ultima visita a la empresa	N°	1	S/ 80.00	S/ 80.00
Adquisición de licencias de software (Visio, Bizagi)	N°	2	S/ 120.00	S/ 240.00
Subtotal				S/ 320.00
Total				**S/ 4,658.00**

Alcance

La presente investigación tiene como alcance el diseño y la aplicación de un modelo basado en las herramientas de Lean Manufacturing 5S, TPM, SMED dirigido a incrementar la efectividad en el proceso de inyección en una empresa de productos plásticos a través de las mejores en los indicadores de disponibilidad, rendimiento, calidad, tiempo de setup, nivel de servicio y OEE.

ALCANCE
• El estudio incluye el análisis en el proceso de moldeo por inyección, que es considerado el proceso crítico y sus actividades se centran en el uso de la máquina inyectora. • La evaluación de los indicadores del OEE tales como disponibilidad, rendimiento, calidad, como base para identificar el parámetro más crítico y las pérdidas a nivel operacional en el proceso de inyección. • El diseño y aplicación de la metodología 5S en el área de inyección, empleando cada una de las S con el propósito de mejorar el área de trabajo. • El diseño y aplicación del TPM, enfocando en dos pilares fundamentales los cuales son mantenimiento autónomo y mantenimiento preventivo para disminuir el tiempo en paradas por averías. • El diseño y aplicación del SMED para reducir, principalmente, los tiempos de montado y desmontado de moldes a través de sus 4 fases. • Se muestra un análisis inicial y final del proceso de inyección a través de indicadores con el objetivo de evaluar el impacto de las herramientas Lean. • Se realiza la simulación del proceso productivo mediante 3 escenarios tales como pesimista, típico y optimista para verificar su comportamiento en distintas condiciones operativas. • La presente investigación adopta un enfoque conceptual de Green Lean Management que se usa como marco teórico y de referencia para analizar el proceso desde una perspectiva de uso eficiente de recursos. • Green Lean es un aporte conceptual y analítico que, si bien no se aplica directamente, su incorporación resulta importante por la limitada evidencia en la

revisión de la literatura en sectores de fabricación de productos plásticos, especialmente en procesos de moldeo por inyección.
LIMITACIONES
• El estudio no incluye el análisis ni la aplicación directa de Green Lean en la implementación de la solución, tales como la medición de impactos ambientales o el uso de indicadores ambientales. • No incluye cambios en el diseño o formulación en los parámetros de los productos como en el diseño de los moldes. • No se incluye la aplicación de Lean en otras áreas de la empresa, sino se enfoca únicamente en el área de moldeo por inyección al ser el proceso más crítico.

Anexo 2

Formato de Bibliometría del artículo de investigación extraído de SCOPUS o WEB OF SCIENCE.

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Anexo 2

Scimago Journal & Country Rank



Anexo 3

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