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Integrating Lean-TPM Strategies for Enhanced Production Efficiency: A Case Study on Textile SMEs in Peru

Martin Olivares-Quiroz
Bachelors in industrial engineering
Facultad de Ingeniería, Universidad de Lima, Perú
19872503@aloe.ulima.edu.pe

John Pedro Zegarra-Solis
Bachelors in industrial engineering
Facultad de Ingeniería, Universidad de Lima, Perú
19880814@aloe.ulima.edu.pe

Abstract

The textile sector, particularly within small and medium-sized enterprises (SMEs) in Latin America, plays a vital role in regional economic development. However, these enterprises face significant challenges, including inefficiencies in production processes and high reprocessing rates that threaten their competitiveness. This research aimed to address these challenges by proposing a Lean-TPM production model specifically designed to optimize knitting and dyeing processes in textile SMEs. The model integrated Lean Manufacturing principles with Total Productive Maintenance (TPM) strategies, focusing on improving operational efficiency, reducing waste, and enhancing equipment reliability. The implementation of the model yielded notable improvements. On-Time Delivery (OTD) rates increased by 102%, reprocessing rates in the dyeing process were reduced by 44%, and audit compliance with the 5S methodology reached 88.10%. These results demonstrate the model's effectiveness in addressing the critical issues faced by textile SMEs. The research contributes significantly to the academic discourse on process optimization in manufacturing and offers practical solutions with socio-economic benefits, including increased productivity and reduced operational costs. Future research should explore the model's adaptability to other manufacturing sectors, encouraging continued innovation in process optimization.

Keywords
Lean Manufacturing, Total Productive Maintenance (TPM), Textile SMEs, Knitting Process, Dyeing Process.

1. Introduction
The small and medium-sized enterprise (SME) textile industry, especially in the manufacture of textiles, plays a crucial role in the global economy. This sector not only contributes significantly to employment but is also fundamental for economic and social development in various regions of the world, including Latin America and Peru. In the global context, textile SMEs account for a considerable share of production and trade, being responsible for a large proportion of the supply of textile products on the international market (Stoll & Ha-Brookshire 2011). In Latin America, this sector has shown remarkable growth, driven by the demand for sustainable and quality products, which has led many SMEs to adopt more innovative and efficient practices (Scafuto et al. 2021). In Peru, textile SMEs are vital to the local economy, generating employment and encouraging skills development in the workforce (Guerra & Camargo 2023). However, despite their importance, these companies face significant challenges that limit their ability to compete in an increasingly demanding global market.

One of the most critical problems faced by SME fabric manufacturers is the low on-time delivery rate (OTD), which is affected by high reprocessing rates in the dyeing process, Frequent problems in weaving machines and constant failures in dyeing machines (Rüttimann & Stöckli 2022). These difficulties not only impact production efficiency, but also affect customer satisfaction and the company's reputation in the market (Udriyah et al. 2019). Lack of proper maintenance and obsolescence of machinery are contributing factors to these problems, resulting in increased operating costs and decreased competitiveness (Quiroz-Flores et al. 2023). In addition, inefficiency in production processes can lead to significant waste of resources, which is particularly worrying in a context where sustainability is increasingly valued by consumers (Rüttimann & Stöckli 2020). It is therefore imperative that textile SMEs address these issues to improve their performance and ensure their long-term viability.

Addressing these problems in the textile SME sector is of paramount importance, as these enterprises are critical to the development of infrastructure and manufacturing in the region. The implementation of effective solutions would not only improve operational efficiency but could also contribute to the creation of a more sustainable and competitive environment (Marques et al. 2017). Adopting continuous improvement methodologies, such as Lean Manufacturing and Total Productive Maintenance (TPM), can be key to addressing today's challenges. These methodologies focus on waste elimination, quality improvement and process optimization, which can result in significant OTD improvement and cost reduction (Quiroz-Flores et al. 2023). In addition, staff training and investment in technology are crucial aspects to ensure that these methodologies are implemented effectively and sustainably (Rüttimann & Stöckli 2020).

Despite the relevance of these issues, there is a significant gap in the literature that specifically addresses problems and solutions for textile SMEs in Latin America. Existing research often focuses on broader contexts or different industries, leaving SMEs with a gap in terms of strategies and production models adapted to their specific needs (Quiroz-Flores et al.2023). This research seeks to fill that gap by developing a production model that integrates Lean Manufacturing and TPM tools, such as 5S, Autonomous Maintenance, and Planned Maintenance. These tools will not only help to improve production efficiency but also foster a culture of continuous improvement within organizations (Rüttimann & Stöckli 2020). By addressing these issues from a theoretical and practical perspective, this research is expected to contribute significantly to the development and sustainability of textile SMEs in Peru and the region.

In conclusion, the importance of the SME textile sector in the global and local economy is undeniable. However, the challenges they face, especially in terms of production efficiency and OTD compliance, require urgent attention. The implementation of continuous improvement methodologies and research on sector-specific solutions are crucial steps to ensure its future competitiveness and sustainability. This research not only seeks to address these problems but also to contribute to the existing body of knowledge, providing a model that can be replicated and adapted by other SMEs in the textile industry.

2. Literature Review

2.1 Lean Manufacturing in Textile SMEs: A Path to Efficiency

The application of Lean Manufacturing methodologies in the textile industry, particularly among small and medium-sized enterprises (SMEs), has garnered significant attention in recent years. Lean Manufacturing focuses on waste reduction and efficiency enhancement, which are critical for the competitiveness of textile SMEs facing global market pressures. Hodge et al. (2011) highlight that the integration of Lean practices in the textile industry has led to substantial improvements in operational efficiency and product quality. Their research indicates that SMEs that adopt Lean principles can streamline their production processes, thereby reducing lead times and enhancing customer satisfaction. Similarly, Moeuf et al. (2017) emphasize the adaptability of Lean principles within the textile sector, noting that these practices can be tailored to fit the unique challenges faced by textile manufacturers. They argue that the implementation of Lean strategies not only improves productivity but also fosters a culture of continuous improvement among employees.

Moreover, Robertsone et al. (2021) explore the specific Lean practices adopted by SMEs in various sectors, drawing parallels with the textile industry. Their findings suggest that practices such as Total Productive Maintenance (TPM) and employee involvement are crucial for successful Lean implementation. This is particularly relevant for textile SMEs, where machine downtime can significantly impact production schedules. Furthermore, Sidhu et al. (2021) discuss the barriers to Lean implementation in the textile industry, identifying factors such as resistance to change and lack of management support as significant hurdles. Their study underscores the need for a comprehensive change management strategy to facilitate the adoption of Lean practices in textile SMEs. Overall, the literature suggests that while challenges exist, the potential benefits of Lean Manufacturing in enhancing efficiency and competitiveness in textile SMEs are substantial.

2.2 Total Productive Maintenance: Ensuring Equipment Reliability

Total Productive Maintenance (TPM) is another critical methodology that has been effectively applied in the textile industry, particularly in the context of SMEs. TPM aims to maximize equipment effectiveness and minimize downtime, which is essential for maintaining production schedules in textile manufacturing. Sidhu et al. (2021) provide empirical evidence of the positive impact of TPM on manufacturing performance in Indian SMEs, highlighting that effective maintenance practices lead to significant improvements in operational efficiency. Their research indicates that SMEs that implement TPM experience reduced machine breakdowns and improved overall equipment effectiveness (OEE).

In a similar vein, Deepthi & Bansal (2022) discuss the integration of TPM within the framework of Industry 4.0, suggesting that the digitalization of maintenance processes can further enhance the effectiveness of TPM strategies. They argue that the synergy between TPM and advanced technologies can lead to predictive maintenance practices, which are particularly beneficial for textile SMEs that rely heavily on machinery. Additionally, Tshiaba et al. (2021) examine the role of TPM in promoting sustainable entrepreneurial performance among textile SMEs, emphasizing that effective maintenance practices contribute to long-term sustainability and competitiveness. Their findings suggest that SMEs that prioritize TPM not only enhance their operational efficiency but also improve their environmental performance.

Moreover, Hossain et al. (2022) explore the relationship between supply chain finance and the performance of textile SMEs, noting that effective maintenance practices, including TPM, can significantly enhance the overall performance of these enterprises. Their research highlights the importance of integrating maintenance strategies with financial management to ensure the sustainability of textile SMEs. Overall, the literature indicates that the implementation of TPM in textile SMEs is crucial for enhancing equipment reliability, reducing downtime, and improving overall operational performance.

2.3 The 5S Methodology: Organizing for Success

The 5S methodology, which focuses on workplace organization and standardization, has been widely adopted in the textile industry to enhance operational efficiency. This methodology consists of five steps: Sort, Set in order, Shine, Standardize, and Sustain, which collectively aim to create a clean and organized work environment. Campoblanco-Carhuachin et al. (2022) emphasize the importance of 5S in reducing non-fulfillment of orders in Peruvian garment SMEs. Their study demonstrates that the implementation of 5S practices leads to improved workflow, reduced waste, and enhanced productivity.

Furthermore, Hossain et al. (2022) explore the application of 5S in the context of sustainable practices among textile SMEs in Bangladesh. Their findings indicate that the adoption of 5S not only improves operational efficiency but also contributes to environmental sustainability by minimizing waste and promoting responsible resource use. Similarly, Deepthi & Bansal (2022) highlight the role of 5S in facilitating the transition to Industry 4.0 within the textile sector. They argue that a well-organized workplace is essential for the successful implementation of advanced manufacturing technologies, which can further enhance productivity and competitiveness.

Additionally, Bhamu & Sangwan (2014) provide a comprehensive review of Lean Manufacturing practices, including 5S, in various industries, emphasizing its relevance in the textile sector. Their research indicates that the successful implementation of 5S requires a commitment from all employees and a supportive organizational culture. Overall, the literature suggests that the 5S methodology is a valuable tool for textile SMEs seeking to enhance operational efficiency, improve workplace organization, and foster a culture of continuous improvement.

2.4 Autonomous Maintenance: Empowering Employees

Autonomous Maintenance (AM) is a critical component of Total Productive Maintenance that empowers employees to take ownership of their equipment and maintenance processes. This methodology has been increasingly applied in the textile industry to enhance equipment reliability and operational efficiency. Hossain et al. (2022) discuss the benefits of AM in promoting employee engagement and accountability in maintenance practices. Their research indicates that when employees are trained to perform routine maintenance tasks, it leads to a greater sense of ownership and responsibility, ultimately resulting in improved equipment performance.

Moreover, Tshiaba et al. (2021) explore the role of AM in enhancing the performance of textile SMEs, emphasizing that empowering employees to participate in maintenance activities can lead to significant improvements in operational efficiency. Their findings suggest that AM not only reduces machine downtime but also fosters a culture of continuous improvement within the organization. Similarly, Sidhu et al. (2021) highlight the importance of AM in promoting sustainable practices among textile SMEs, noting that effective maintenance practices contribute to long-term sustainability and competitiveness.

Furthermore, Tshiaba et al. (2021) examine the relationship between AM and employee performance in textile SMEs, emphasizing that training and empowering employees in maintenance activities can lead to enhanced productivity and job satisfaction. Their research underscores the need for a supportive organizational culture that encourages employee involvement in maintenance practices. Overall, the literature indicates that the implementation of Autonomous Maintenance in textile SMEs is crucial for enhancing equipment reliability, reducing downtime, and improving overall operational performance.

2.5 Preventive Maintenance: A Proactive Approach

Preventive Maintenance (PM) is a proactive approach that aims to prevent equipment failures before they occur, thereby ensuring the smooth operation of textile manufacturing processes. The application of PM in textile SMEs has been shown to significantly enhance operational efficiency and reduce downtime. Sidhu et al. (2021) provide empirical evidence of the positive impact of PM on manufacturing performance in Indian SMEs, highlighting that effective preventive maintenance practices lead to significant improvements in operational efficiency. Their research indicates that SMEs that implement PM experience reduced machine breakdowns and improved overall equipment effectiveness (OEE). In a similar vein, Hossain et al. (2022) discuss the integration of PM within the framework of Industry 4.0, suggesting that the digitalization of maintenance processes can further enhance the effectiveness of PM strategies. They argue that the synergy between PM and advanced technologies can lead to predictive maintenance practices, which are particularly beneficial for textile SMEs that rely heavily on machinery. Additionally, Tshiaba et al. (2021) explore the relationship between supply chain finance and the performance of textile SMEs, noting that effective maintenance practices, including PM, can significantly enhance the overall performance of these enterprises.

Moreover, Tshiaba et al. (2021) examine the role of PM in promoting sustainable entrepreneurial performance among textile SMEs, emphasizing that effective maintenance practices contribute to long-term sustainability and competitiveness. Their findings suggest that SMEs that prioritize PM not only enhance their operational efficiency but also improve their environmental performance. Overall, the literature indicates that the implementation of Preventive Maintenance in textile SMEs is crucial for enhancing equipment reliability, reducing downtime, and improving overall operational performance.

3. Methods

3.1 Basis of the Proposed Model

In Figure 1, the Lean-TPM production model aimed to optimize the knitting and dyeing processes within textile SMEs by integrating Lean Manufacturing principles with Total Productive Maintenance (TPM) practices. The model focused on systematically addressing the inefficiencies and challenges inherent in these processes to improve overall productivity and operational performance. Lean Manufacturing principles were applied to eliminate waste and enhance process flow, while the TPM approach was employed to ensure that equipment and machinery were maintained at optimal performance levels, minimizing downtime and defects. The model was structured around four key components: planification, the 5S methodology, total maintenance productivity, and ongoing evaluation and adjustments. This comprehensive approach allowed for the alignment of production activities with strategic objectives, fostering a culture of continuous improvement and operational excellence. By implementing this model, the aim was to achieve a higher level of efficiency and reliability in the textile production processes, ultimately leading to better customer satisfaction and competitive advantage for the SMEs involved. The model served as a structured framework for guiding the transformation of textile operations, ensuring that all critical aspects of production were systematically addressed and optimized.

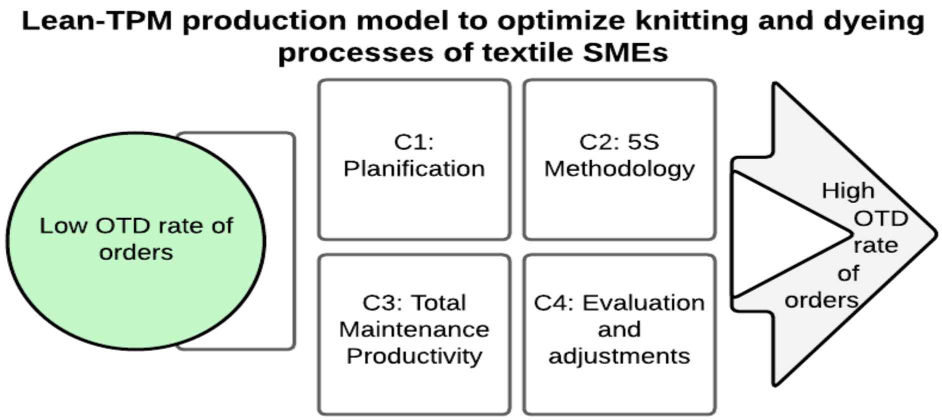

Figure 1. Proposed Model

3.2 Description of the model components

The proposed Lean-TPM production model represents a significant contribution to the existing body of literature on optimizing manufacturing processes in small and medium-sized enterprises (SMEs) within the textile industry. This model addresses the specific challenges faced by textile SMEs, particularly in the knitting and dyeing processes, which are often characterized by inefficiencies, high reprocessing rates, and equipment failures. By integrating the principles of Lean Manufacturing and Total Productive Maintenance (TPM), the model offers a holistic approach to improving operational performance, reducing waste, and enhancing the reliability of production equipment. The Lean philosophy, with its emphasis on eliminating non-value-added activities and streamlining processes, combined with TPM's focus on maximizing the effectiveness of machinery through proactive maintenance, forms the foundation of this model. The model is structured into four key components: planification, the 5S methodology, total maintenance productivity, and evaluation and adjustments. Each component is designed to address specific aspects of the production process, ensuring that the model is comprehensive in its approach to process optimization. This detailed explanation will provide a step-by-step analysis of each component of the model, highlighting how it contributes to the overall improvement of textile production in SMEs.

C1: Planification: Setting the Foundation for Lean-TPM Implementation

The first component of the Lean-TPM model is planification, which serves as the foundation for the successful implementation of Lean and TPM practices. In this phase, strategic planning was carried out to align the production processes with the overall business objectives of the SME. The goal was to create a clear roadmap for the implementation of the model, ensuring that all stakeholders were aligned and committed to the process. The planning phase involved a thorough analysis of the existing production processes, identifying key areas where Lean and TPM principles could be applied to achieve significant improvements. This stage was critical in establishing a baseline for measuring the impact of the model, as well as in setting realistic and achievable targets for process optimization. The planning process also involved the identification of key performance indicators (KPIs) that would be used to monitor progress and measure the success of the model. By setting clear goals and objectives, the planification component ensured that the implementation of Lean and TPM practices was systematic and aligned with the overall strategic vision of the SME. This stage also included the development of detailed action plans, outlining the specific steps that would be taken to implement the model and achieve the desired outcomes.

C2: 5S Methodology: Creating an Organized and Efficient Workplace

The second component of the Lean-TPM model is the implementation of the 5S methodology, which is a fundamental Lean tool aimed at creating an organized, clean, and efficient workplace. The 5S methodology is based on five Japanese principles: Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize), and Shitsuke (Sustain). These principles were applied to the textile production environment to eliminate waste, reduce inefficiencies, and create a safer and more productive workspace. In the context of the textile SMEs, the 5S methodology was used to organize workstations, streamline workflows, and ensure that all tools and materials were easily accessible and properly maintained. This not only improved the efficiency of the production process but also contributed to the reduction of defects and reprocessing rates. The implementation of the 5S methodology also fostered a culture of continuous improvement, where employees were encouraged to take ownership of their work environment and actively participate in maintaining high standards of cleanliness and organization. The 5S methodology was particularly effective in addressing the challenges associated with the dyeing and knitting processes, where clutter and disorganization can lead to significant delays and errors. By creating a more organized and efficient workplace, the 5S methodology played a crucial role in enhancing the overall productivity and quality of the textile production process.

C3: Total Maintenance Productivity: Ensuring the Reliability of Equipment
The third component of the Lean-TPM model is Total Maintenance Productivity (TMP), which focuses on ensuring the reliability and effectiveness of the production equipment. In textile SMEs, machinery plays a critical role in the production process, and any breakdowns or failures can lead to significant disruptions and losses. TMP is based on the TPM philosophy, which emphasizes proactive and preventive maintenance to minimize equipment downtime and maximize its operational efficiency. In this model, TMP was implemented by establishing a comprehensive maintenance program that included regular inspections, preventive maintenance, and employee training. The maintenance program was designed to identify potential issues before they lead to equipment failures, ensuring that the machinery was always in optimal working condition. This component also involved the development of maintenance schedules and checklists, which were used to track the performance and condition of the equipment. By ensuring that the machinery was properly maintained and operated at peak efficiency, TMP contributed to the reduction of reprocessing rates, the improvement of product quality, and the overall reliability of the production process. The TMP component also emphasized the importance of involving all employees in the maintenance process, creating a sense of ownership and responsibility for the equipment among the workforces. This holistic approach to equipment maintenance not only improved the reliability of the production process but also contributed to the overall sustainability of the SME.

C4: Evaluation and Adjustments: Continuous Improvement and Adaptation
The final component of the Lean-TPM model is evaluation and adjustments, which focuses on the continuous improvement and adaptation of the production process. This component is based on the Lean philosophy of continuous improvement (Kaizen), which emphasizes the importance of regularly reviewing and refining processes to achieve incremental gains in efficiency and quality. In this model, evaluation and adjustments were carried out through regular performance reviews, where the KPIs established during the planification phase were used to assess the effectiveness of the Lean-TPM implementation. These reviews provided valuable insights into the areas where the model was successful, as well as those that required further improvement. Based on the findings from these evaluations, adjustments were made to the production processes, ensuring that the model remained flexible and responsive to changing conditions. This component also involved the collection and analysis of data from the production floor, which was used to identify trends, patterns, and opportunities for improvement. By continuously evaluating and adjusting the production process, the Lean-TPM model ensured that the SME was able to maintain high levels of productivity, quality, and efficiency over time. The evaluation and adjustments component also played a crucial role in sustaining the gains achieved through the implementation of the model, ensuring that the improvements were not just temporary but were embedded into the fabric of the SME's operations.

In conclusion, the Lean-TPM production model provided a comprehensive framework for optimizing the knitting and dyeing processes in textile SMEs. By integrating Lean Manufacturing principles with Total Productive Maintenance practices, the model addressed the specific challenges faced by these SMEs, improving their operational performance, reducing waste, and enhancing the reliability of their production equipment. Each component of the model—planification, 5S methodology, total maintenance productivity, and evaluation and adjustments—played a critical role in achieving these outcomes. The systematic approach to process optimization ensured that the SME was able to achieve significant improvements in productivity, quality, and efficiency, ultimately leading to greater customer satisfaction and competitive advantage in the textile industry.

3.3 Model Indicators
To evaluate the Lean-TPM production model's impact on optimizing knitting and dyeing processes in textile SMEs, specialized metrics were created. These metrics were tailored to monitor and assess performance throughout the case study, offering a solid foundation for analyzing critical elements of textile operations in an SME setting. This

systematic approach enabled a detailed investigation of key performance indicators, such as the dyeing process reprocessing rate, on-time delivery (OTD), and the amount of material reprocessed in the knitting industry. This thorough assessment ensured effective monitoring and enhancement of the production processes.

OTD (On-Time Delivery): Measures the percentage of orders delivered on or before the agreed delivery date, reflecting the efficiency of the production process in meeting customer deadlines.

$$\text{OTD}(\%) = \left(\frac{\text{Number of On-Time Deliveries}}{\text{Total Number of Deliveries}}\right) \times 100 \tag{1}$$

Kg rate with knitting problems: Represents the percentage of total production that experienced knitting defects, indicating the quality level of the knitting process.

$$\text{Kg rate with knitting problems}(\%) = \left(\frac{\text{Kg with Knitting Problems}}{\text{Total Kg Produced}}\right) \times 100 \tag{2}$$

Reprocessing rate in the dyeing process: Measures the percentage of production requiring reprocessing due to defects in the dyeing process, reflecting process efficiency and quality control.

$$\text{Reprocessing rate in the dyeing process}(\%) = \left(\frac{\text{Kg Reprocessed in Dyeing}}{\text{Total Kg Dyed}}\right) \times \mathbf{100} \tag{3}$$

Audit 5S: Indicates the percentage score obtained in a 5S audit, reflecting the level of workplace organization and adherence to the 5S methodology.

$$\text{Audit 5S}(\%) = \left(\frac{\text{5S Score Obtained}}{\text{Total Possible 5S Score}}\right) \times \mathbf{100} \tag{4}$$

4. Validation

4.1 Initial Diagnosis

In Figure 2, the problem tree illustrates the summary of the diagnostic analysis conducted in the case study to identify the reasons and root causes contributing to the research problem. The central issue identified was the low On-Time Delivery (OTD) rate of orders, with a recorded rate of 38.79%, significantly below the industry standard of 80%. This discrepancy created a technical gap, resulting in an economic impact estimated at 100,229 USD annually, equating to 4.73% of the company's annual revenue. The diagnostic process revealed that 38.5% of the problem was due to a high reprocessing rate in the dyeing process, primarily caused by dirt stains on fabrics (29.8%) and inadequate cleaning during product changes (5.4%). Additionally, 31.1% of the issue stemmed from problems in knitting machines, attributed to poor maintenance (16.3%), the mixing of yarn batches (7.7%), and lint contamination (7.1%). Furthermore, failures in dyeing machines contributed 28.6% to the problem, with water and fluid leakage (22.8%) and pump seal failures (5.8%) being the primary root causes. This structured approach provided a comprehensive understanding of the underlying issues, guiding the formulation of targeted interventions for process improvement within the textile SME.

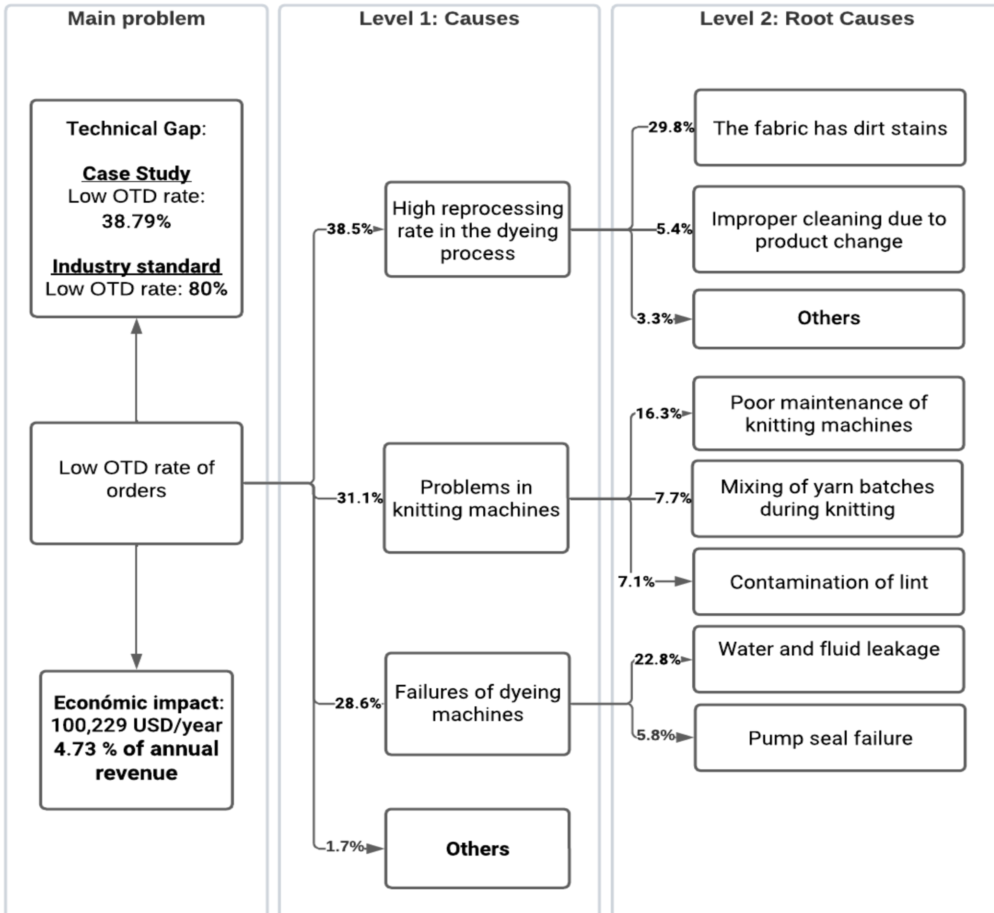

Figure 2. Problem Tree

4.2 Implementation of the model in the case study

The implementation of the model proposed in this case study was carried out through a phased process approach with the aim of optimizing textile processes in a small and medium-sized enterprise (SME) specializing in polyester fabric weaving and dyeing. This design was structured in four distinct phases, each of which focused on the implementation of Efficient Manufacturing and Total Productive Maintenance (TPM) methodologies to address identified inefficiencies in production processes. The solution design was based on quantitative data, ensuring that each phase is supported by measurable results and improvements.

Phase 1: Formation of the Lean Manufacturing Team and Resource Allocation

The first phase of the solution focused on the formation of a specialized Lean Manufacturing team, which included members from various departments within the organization. The Process Engineering department took the lead in this initiative, with the option to hire an external consultant specializing in Lean Manufacturing if necessary. This phase was essential for establishing a solid foundation for the subsequent implementation of Lean practices.

A detailed cost analysis was conducted to allocate the necessary resources effectively. The resources identified included computers and office supplies for planning, as well as toolkits for taking measurements, samples, and marking zones. The planning and allocation of these resources were crucial in ensuring that the team had all the necessary tools to implement the improvements efficiently. Additionally, the cost analysis provided a clear picture of the investment required, which was vital for gaining approval from upper management.

Phase 2: Implementation of the 5S Methodology to Improve Workplace Organization

In the second phase, the focus was on implementing the 5S methodology, a fundamental Lean tool aimed at improving workplace organization and cleanliness. Initially, a diagnostic survey was conducted among all staff to assess their perception of the current state of order and cleanliness in the workplace. The survey revealed that only 5.95% of the staff perceived the work areas as orderly and clean, indicating a significant need for improvement.

Following this, the 5S principles were implemented through rigorous training sessions, the development of instructional materials, and the establishment of ongoing audits. These steps resulted in a remarkable improvement in workplace organization. By the third audit, which was conducted one month after the initial implementation, the perception of orderliness had increased to 33.33%, later reaching 60.71%, 76.19%, and eventually 88.10%. This significant improvement demonstrated the effectiveness of the 5S methodology in transforming the work environment, thereby contributing to the overall efficiency of the production processes.The implementation of the 5S methodology not only improved workplace organization but also led to a reduction in rework rates and an improvement in on-time delivery (OTD) rates. These improvements were quantitatively measured through the regular audits, providing clear evidence of the benefits of the 5S implementation.

Figure 3 illustrates the compliance results from a series of internal audits conducted to assess the implementation of the 5S methodology at the Bocanegra plant. The audits were conducted over six different periods between May 2022 and October 2022. The data shows a progressive improvement in compliance with 5S standards. In the first audit (May 2022), the compliance rate was notably low, with only 5.95% of the items audited meeting the 5S criteria. This low compliance indicates a significant need for improvement in workplace organization and cleanliness. By the second audit (June 2022), the compliance rate had slightly improved to 8.33%. The third audit (July 2022) showed a more substantial increase in compliance, reaching 33.33%, reflecting the beginning of a positive trend.

As the 5S implementation continued, the fourth audit (August 2022) recorded a compliance rate of 60.71%, marking a significant leap in adherence to the 5S standards. The fifth audit (September 2022) continued this upward trajectory, with compliance reaching 76.19%. By the sixth and final audit (October 2022), the compliance rate had improved to an impressive 88.10%. This steady increase in compliance demonstrates the effectiveness of the 5S implementation over time, with substantial improvements in workplace order and cleanliness achieved through systematic efforts.

CUMPLIMIENTO AUDITORIA INTERNA - Implementacion de orden y limpieza (5S) - PLANTA BOCANEGRA						
CONCEPTO	**1ra auditoría (Mayo 2022)**	**2da auditoría (Junio 2022)**	**3ra auditoría (Julio 2022)**	**4ta auditoría (Agosto 2022)**	**5ta auditoría (Setiembre 2022)**	**6ta auditoría (Octubre 2022)**
Número de puntos **SI** cumplidos	5	7	28	51	64	74
Número de puntos **NO** cumplidos	79	77	56	33	20	10
Total items auditados	84	84	84	84	84	84
PORCENTAJE DE CUMPLIMIENTO	**5.95%**	**8.33%**	**33.33%**	**60.71%**	**76.19%**	**88.10%**

Figure 3. Compliance audits 5S

Figure 4 shows a comparison of the fabric preparation area before and after the implementation of the 5S methodology. On the left side, the area is depicted before the 5S implementation, where the workspace appears cluttered and disorganized. Fabrics are haphazardly covered and stored, with no clear system in place for order or cleanliness, indicating a lack of effective management in this area.

On the right side, the image shows the same area after the 5S implementation. The workspace is notably more organized, with fabrics properly covered and stored, demonstrating a significant improvement in order and cleanliness. The transformation reflects the positive impact of the 5S methodology on the work environment, resulting in a more efficient and well-maintained space. This visual comparison underscores the effectiveness of the 5S implementation in enhancing workplace organization and efficiency.

Figure 4. Area of fabric preparation before and after the 5S implementation

Phase 3: Implementation of Total Productive Maintenance (TPM)
The third phase of the solution involved the implementation of Total Productive Maintenance (TPM), aimed at enhancing the reliability and availability of the production equipment. This phase was critical in addressing the gaps in maintenance management, which had been identified as a major contributor to production inefficiencies.TPM was introduced through comprehensive training sessions for all operational staff. These sessions covered the basic principles of TPM, including autonomous and preventive maintenance. The training was crucial in equipping the staff with the knowledge and skills necessary to carry out basic maintenance tasks independently, thereby reducing the dependency on specialized maintenance personnel.

One of the key aspects of this phase was the transfer of specific maintenance tasks, such as internal cleaning of machines and seal replacement in pumps, to the operators. This transfer of responsibilities was part of the autonomous maintenance initiative, which aimed to empower the operators to take ownership of the equipment they worked with. The implementation of preventive maintenance schedules further contributed to the reduction of equipment downtime, which in turn improved the overall efficiency of the production line.The quantitative impact of the TPM implementation was significant. The reduction in equipment downtime led to a measurable increase in machine availability, which directly contributed to the improvement in production efficiency. Additionally, the successful implementation of TPM played a crucial role in reducing the rework rates and improving the OTD rates, further validating the effectiveness of the Lean-TPM integration.

Figure 5 presents an analysis of the transfer of preventive maintenance tasks within the textile production facility. The table categorizes specific maintenance activities and evaluates whether operators are willing and capable of performing these tasks independently, or if the maintenance department needs to intervene.The first task, internal machine cleaning, shows that operators are both willing and able to perform the task, which is essential for eliminating the root cause of inadequate cleaning after product changes. The second task, changing seals in pumps, also shows that operators are prepared to handle the task, effectively addressing issues related to seal failures in pumps.

However, the third and fourth tasks, which involve the maintenance of knitting machines and the maintenance of dyeing machines, respectively, require more specialized knowledge and experience. The analysis indicates that these tasks should remain under the purview of the maintenance department due to their complexity.

The observations column provides insights into the reasons why certain tasks are either transferred to the operators or retained by the maintenance department. The root causes that these maintenance activities aim to eliminate are primarily related to equipment reliability and process efficiency, such as reducing contamination during production and preventing mechanical failures. This structured approach ensures that maintenance tasks are appropriately assigned, thereby improving overall operational efficiency and reducing downtime.

Análisis de transferencia de tareas de mantenimiento preventivo

Item	Descripción de trabajo	El operador esta dispuesto a realizar el trabajo	El Dpto. de mtto busca que el operador lo realice	El operador puede realizar los trabajos	O}bservaciones	Causa raiz a eliminar
1	Limpieza interna de máquina	Si	Si	Si		Limpieza inadecuada por cambio de producto
2	Cambio de sellos en bombas	Si	Si	Si		Falla en el sello de bombas
4	Mantenimiento maquina de tejeduría	No	No	No	Se necesita conocimiento y experiencia	
5	Mantenimiento máuina de tintoreria	Si	No	No	Se necesita conocimiento y experiencia	

Figure 5. Transfer of maintenance tasks

Figure 6 displays a detailed schedule for the preventive maintenance plan of various equipment within the textile production facility. The table is organized by equipment type and sub-type, listing the specific maintenance activities required, their frequency, and the criticality of each task.The equipment is divided into categories such as tubulature, valves, and different types of motors. Each activity, such as general cleaning, mechanical inspections, or the replacement of seals, is scheduled at specific intervals, typically every two or three months. The table differentiates between tasks deemed "critical" and "normal," emphasizing the importance of prioritizing certain maintenance activities to prevent significant disruptions in the production process.

The grid on the right side of the figure represents the planned maintenance activities for the months of July through December. Each colored cell corresponds to a scheduled maintenance task, with the color indicating whether the task is critical (yellow) or normal (blue). The grid provides a clear visual representation of the maintenance schedule, ensuring that all necessary activities are accounted for and properly timed throughout the second half of the year.This scheduling tool is crucial for maintaining equipment reliability and ensuring that preventive maintenance is conducted systematically, thereby reducing the likelihood of unexpected breakdowns and extending the lifespan of the machinery.

Equipo	SubEquipo	Actividd	Frecuencia	tipo de actividad	carácter	Programación: Julio, Agosto, Setiembre, Octubre, Noviembre, Diciembre (1 2 3 4)
Máquina de tintoreria	Tuberias y válvulas	Limpieza general	2 meses	Mecánica	Normal	P
						E
	Bomba de recirculación	limpieza de rodamientos	3 meses	Mecánica	Normal	P
						E
		Verificar cambio de rodamientos	3 meses	Mecánica	Normal	P
						E
		Verificar cambio de sellos	3 meses	Mecánica	Crítico	P
						E
		limpieza impulsor	2 meses	Mecánica	Normal	P
						E
	Motor	Inspeccion de vibracion y ruido	2 meses	Eléctrica	Crítico	P
						E
		Limpieza general	2 meses	Eléctrica	Critico	P
						E
		Limpieza de caja de conexión elec.	3 meses	Eléctrica	Critico	P
						E
Máquina de tejeduria	Ventiladores	Limpieza general	2 meses	Mecánica	Normal	P
						E
	Tuberias	Limpieza general	2 meses	Mecánica	Normal	P
						E
	Sensores	Limpieza general	3 meses	Eléctrica	Critico	P
						E
	Motor	Inspeccion de vibracion y ruido	2 meses	Eléctrica	Critico	P
						E
		Limpieza general	2 meses	Eléctrica	Critico	P
						E
		Limpieza de caja de conexión elec.	3 meses	Eléctrica	Critico	P
						E
	Talero eléctrico	Limpieza general	6 meses	Eléctrica	Normal	P
						E

Figure 6. Scheduling preventive maintenance plan

Phase 4: Evaluation and Continuous Improvement

The final phase of the solution focused on evaluating the progress made during the implementation of Lean and TPM tools and ensuring continuous improvement. This phase was essential for identifying areas that required further improvement and for planning the extension of successful practices to other areas of the company.The evaluation process involved continuous monitoring of key performance indicators (KPIs) that had been established during the planning phase. These KPIs included measures of workplace organization, machine availability, rework rates, and OTD rates. The regular monitoring of these indicators provided valuable insights into the effectiveness of the implemented solutions and highlighted areas where further improvements were needed.One of the key outcomes of this phase was the identification of opportunities for extending the successful practices implemented in the knitting and dyeing processes to other areas of the company. This extension was planned to maximize the benefits of the Lean-TPM integration and ensure that the improvements were sustained over time.

The continuous improvement process also involved making adjustments to the implemented solutions based on the feedback received from the monitoring process. These adjustments were crucial in ensuring that the solutions remained relevant and effective in addressing the ongoing challenges faced by the company.The overall impact of the evaluation and continuous improvement phase was significant. The improvements in workplace organization, machine availability, rework rates, and OTD rates were sustained over time, leading to long-term benefits for the company. These benefits included increased productivity, reduced costs, and improved customer satisfaction.

5. Results

Table 1 presents the key results from the validation of the proposed Lean-TPM model aimed at addressing the research problem in the knitting and dyeing processes within textile SMEs. The implementation of this model resulted in a significant improvement in various indicators. Specifically, the On-Time Delivery (OTD) rate increased by 102%, demonstrating a marked enhancement in meeting delivery schedules. Additionally, the kilogram rate of knitting problems was reduced by 81%, indicating a substantial decrease in production defects. The reprocessing rate in the dyeing process also saw a considerable reduction of 44%, highlighting improvements in process efficiency. Furthermore, the 5S audit score improved by 80%, reflecting better organization and cleanliness in the production environment. These outcomes validate the effectiveness of the Lean-TPM model in optimizing the operational performance of the involved processes.

Table 1. Results of validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
OTD	%	38.79	80	78.4	102%
Kg rate with knitting problems	%	8.7	2	1.69	-81%
Reprocessing rate in the dyeing process	%	12.5	7	7	-44%
Audit 5S	%	48.9	90	88.1	80%

6. Conclusions.

The study developed a comprehensive Lean-TPM production model to optimize the knitting and dyeing processes within textile SMEs, addressing critical inefficiencies in production. The model's implementation resulted in significant improvements in key performance indicators: On-time delivery (OTD) rates increased by 102%, reprocessing rates in the dyeing process were reduced by 44%, and audit compliance with the 5S methodology reached 88.10%. These findings validate the model's effectiveness in enhancing operational efficiency, reducing waste, and ensuring higher reliability in production equipment.

The importance of this research lies in its focus on a sector that is crucial to the economic development of many regions, particularly in Latin America. Textile SMEs face unique challenges, including outdated machinery, inefficient processes, and high reprocessing rates, which hinder their competitiveness in the global market. This study's approach not only addresses these challenges but also provides a structured methodology for continuous improvement, which is essential for the long-term sustainability of these enterprises.The contributions of this research to the field of Industrial Engineering are substantial. It bridges a gap in the existing literature by providing a detailed, context-specific model that integrates Lean Manufacturing principles with Total Productive Maintenance (TPM) strategies. The model offers a holistic approach that can be adapted and applied to other manufacturing sectors facing similar challenges. Furthermore, the research highlights the importance of employee involvement and systematic maintenance in achieving operational excellence, reinforcing the value of Lean and TPM in modern manufacturing.

Final observations suggest that while the Lean-TPM model has demonstrated significant benefits, its implementation requires a strong commitment from management and active participation from all levels of the organization. Future studies should explore the adaptability of this model to other industries and regions, considering the unique challenges and opportunities they present. Additionally, further research could investigate the long-term impacts of this model on organizational culture and employee satisfaction, providing a more comprehensive understanding of its benefits.The study calls for action in encouraging other researchers and practitioners to explore innovative solutions tailored to the specific needs of SMEs in different sectors. The success of the Lean-TPM model in this study serves as a compelling example of how targeted interventions can lead to significant improvements in productivity and efficiency. There is a critical need for continued exploration of how Lean and TPM methodologies can be adapted to address the evolving challenges of modern manufacturing, ensuring that SMEs can remain competitive in an increasingly complex global market.

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Biographies

Martin Olivares-Quiroz is an MBA graduate with honors from Universidad del Pacifico and an industrial engineer from Universidad de Lima. With 28 years of experience in multinational and SME environments, he specializes in strategy, innovation, and digital transformation, particularly in Green Digital Skills. Martin excels in product development, marketing, and process improvement, and is an expert in AI applications in education and marketing. He currently serves as a Key Account Manager, General Director, Marketing Director, and university lecturer in various institutions.

John Pedro Zegarra-Solis has an MBA from the European University of Madrid, he studied Industrial Engineering at the University of Lima and with several specializations around Marketing. I have 28 years of experience in the Retail Sector, occupying almost all positions in the Supply Chain in a Multinational company. John stands out in the Retail world, in the development and introduction of new products and business management. I have been Logistics Manager, Product Manager, Commercial Director, University Professor and currently I am leading a training project for a new retailer specialized in household appliances in Peru.