5th Asia Pacific Conference on Industrial Engineering and Operations Management
Tokyo, Japan, September 10-12, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AP05.20240101
Published: September 10, 2024

Enhancing Operational Efficiency in Textile SMEs: Integrating Lean Manufacturing and Total Productive Maintenance for Superior Performance

Ignacio Herrera-Barreda
Bachelors in industrial engineering
Facultad de Ingeniería, Universidad de Lima, Peru
20170709@aloe.ulima.edu.pe

Abstract

The textile and garment sector in Peru is crucial to the economy, contributing to productive diversification and generating foreign exchange through exports. However, SMEs in this sector face significant operational challenges, including inefficient machine setup, high rates of rework, frequent breakdowns, and excessive sewing times due to lack of standardized processes. Addressing these issues is essential to enhance their competitiveness and sustainability. The proposed model integrates Lean Manufacturing and Total Productive Maintenance (TPM) tools, such as 5S, Standardized Work, SMED, and Autonomous Maintenance, aiming to optimize production processes, reduce waste, and improve operational efficiency. This approach targeted deficiencies in machine setup, operational errors, and inadequate maintenance practices prevalent in the sector. The implementation of the model demonstrated significant improvements. Operational efficiency increased by 32.01%, defective product rates decreased by 29.81%, and setup times were reduced by 27.26%. These results were achieved through the systematic application of Lean and TPM principles, which streamlined processes, minimized downtime, and enhanced overall productivity. The research's impact extends beyond operational improvements, contributing to the academic literature by filling a knowledge gap in the application of Lean and TPM tools in textile SMEs. Socioeconomically, the model promotes job creation, preserves cultural traditions, and enhances the competitiveness of SMEs, fostering economic growth in the region.
This study underscores the importance of adopting efficient production practices in the textile sector. It calls for further research to explore the integration of advanced technologies and methodologies to sustain and enhance these improvements. Scholars and practitioners are encouraged to build on these findings to drive innovation and growth in the industry.

Keywords
Lean Manufacturing, Total Productive Maintenance, Textile SMEs, Operational Efficiency, Process Optimization.

1. Introduction
The importance of the SMEs in the textile and garment sector worldwide is undeniable, as these companies play a crucial role in the global economy by generating employment, driving innovation, and significantly contributing to international trade (DIVRIK & Baykal 2024). In Latin America, textile SMEs represent a fundamental part of the industry, serving as a driving force for economic and social development in the region (Ali 2022). In Peru, specifically, SMEs in the textile and garment sector are pillars of the economy, contributing to productive diversification and generating foreign exchange through their exports (Palacios-Mateo et al. 2021). These companies not only generate wealth but also preserve cultural traditions and foster creativity in garment design (Hrouga & Michel 2023).

The production problems faced by SMEs in the textile and garment sector are related to deficiencies in machine setup when changing products, operational errors that generate rework, breakdowns due to poor maintenance, and excessive sewing times due to a lack of standardized work (Juanga-Labayen et al. 2022). These difficulties negatively impact the efficiency and profitability of the companies, affecting their competitiveness in an increasingly demanding market (Soares 2024). The lack of standardized processes and adequate machinery maintenance leads to lower product quality, delivery delays, and additional costs for unplanned repairs (Verma 2023). These operational challenges can limit the growth of SMEs and jeopardize their long-term sustainability (Boschmeier et al. 2023).

Addressing the problems of SMEs in the textile and garment sector is vitally important to ensure their survival and growth in an increasingly competitive business environment (Ta et al. 2022). By addressing deficiencies in machine setup, operational errors, and breakdowns due to inadequate maintenance, companies can improve their efficiency, reduce costs, and increase their responsiveness to market demands (Tian et al. 2022). Implementing more efficient and sustainable production practices benefits individual companies and contributes to the economic and social development of the communities where they operate, promoting job creation and the well-being of their workers (Zaman et al. 2021). Improving production management in textile SMEs impacts not only their profitability but also their reputation and market positioning, which can open new business and expansion opportunities (Lei et al. 2023).

Despite the relevance of the identified problems in SMEs in the textile and garment sector, there is a significant knowledge gap in the literature regarding the application of specific tools to comprehensively address these difficulties (Lin et al. 2022). The proposed research will focus on developing a production model based on Lean Manufacturing and TPM tools, such as 5S, Standardized Work, SMED, and Autonomous Maintenance, to optimize production processes, reduce waste, and improve operational efficiency in textile SMEs (Stefan et al. 2022). By filling this knowledge gap, the research aims to contribute to the academic literature and provide companies in the sector with practical tools to improve their performance and competitiveness in a globalized and constantly evolving market (Singhal 2023).

2. Literature Review

2.1 Application of Lean Manufacturing Methodology in Textile and Clothing SMEs

The Lean Manufacturing methodology has been extensively studied in the context of small and medium-sized enterprises (SMEs) in the textile and clothing sector. Research such as that by Sarasi et al. (2023) has explored sustainable supply chains in the textile and apparel industry in Indonesia, highlighting both opportunities and challenges. These studies are based on systematic literature reviews and content analysis to thoroughly understand how the implementation of lean practices can enhance efficiency and sustainability in textile SMEs (Sarasi et al., 2023). **Furthermore**, the systematic review by Forno et al. (2021) on Industry 4.0 in the textile and apparel sector emphasizes the importance of adopting robust methodological approaches to map the current state and future trends in the application of lean technologies in these companies (Forno et al. 2021).

2.2 Application of SMED in Textile and Clothing SMEs' Manufacturing Processes

The SMED (Single-Minute Exchange of Die) methodology has proven beneficial in optimizing manufacturing processes in textile and clothing SMEs. Studies such as that by Kose et al. (2022) have applied axiomatic design to develop a lean autonomous maintenance system in the textile industry, underscoring the importance of structured approaches to enhance operational efficiency in this sector (Kose et al. 2022). Additionally, 's (2022) research on surgical mask production during the COVID-19 pandemic highlights how the application of methodologies like Kaizen and 5S can lead to continuous improvements in manufacturing processes, which is crucial for textile SMEs seeking to streamline their operations (Demirtaş et al. 2022).

2.3 Application of Autonomous Maintenance in Textile and Clothing SMEs' Manufacturing Processes

Autonomous Maintenance has been a subject of interest in research related to textile and clothing SMEs. Studies such as that by Kose et al. (2022) have explored axiomatic design to develop a lean autonomous maintenance system in the textile industry, emphasizing the importance of involving employees in proactive machinery and equipment management to enhance efficiency and reduce production disruptions (Kose et al. 2022). Furthermore, 's (2021) research on a machine learning framework for real-time machine health monitoring system in SMEs highlights how autonomous maintenance can be enhanced by intelligent technologies to ensure operational continuity (Velmurugan et al.2021).

2.4 Application of 5S in Textile and Clothing SMEs' Manufacturing Processes

The 5S methodology, known for its focus on workplace organization and cleanliness, has been a subject of research in the context of textile and clothing SMEs. Studies such as 's (2022) work on surgical mask production during the COVID-19 pandemic emphasize how the application of 5S can contribute to continuous improvement in manufacturing processes, crucial for ensuring quality and efficiency in SME operations in this sector (Demirtaş et al.2022). Additionally, 's (2021) research on the future of the textile industry in Iran highlights how research methods like MICMAC and soft operational research can provide valuable insights for the effective implementation of practices like 5S in textile SMEs (Fathi et al. 2021).

2.5 Application of Standardized Work in Textile and Clothing SMEs' Manufacturing Processes

Work standardization, a key component of Lean methodology, has been of interest in research related to textile and clothing SMEs. Studies such as .'s (2022) work on surgical mask production during the COVID-19 pandemic underscore the importance of establishing standardized processes to ensure consistency and efficiency in textile product manufacturing (Demirtaş et al. 2022). Furthermore, 's study (2023) on the impact of debt and equity financing on firm performance during the COVID-19 pandemic highlights how process standardization can be essential for maintaining competitiveness and quality in textile and clothing SME operations (Bandara 2023)..

3. Methods

3.1 Basis of the Proposed Model

Figure 1 shows a production model based on the philosophies of Lean Manufacturing and Total Productive Maintenance (TPM). This model aimed to improve operational efficiency and quality in production processes by reducing waste and optimizing equipment maintenance. Lean Manufacturing focused on eliminating non-value-added activities, implementing tools such as 5S to maintain order and cleanliness in the work environment, and SMED to reduce machine setup times. On the other hand, TPM promoted active worker participation in autonomous maintenance, encouraging responsibility and care for machines by operators. The model integrated daily management and audit to ensure compliance with standards, and indicator management to monitor performance and guide continuous improvements. Through standardized work, the aim was to establish consistent and efficient operating methods to achieve the reduction of machine failures and the optimization of setup time. Together, these practices sought to create an organized and standardized work environment, thereby improving productivity and the quality of the production process.

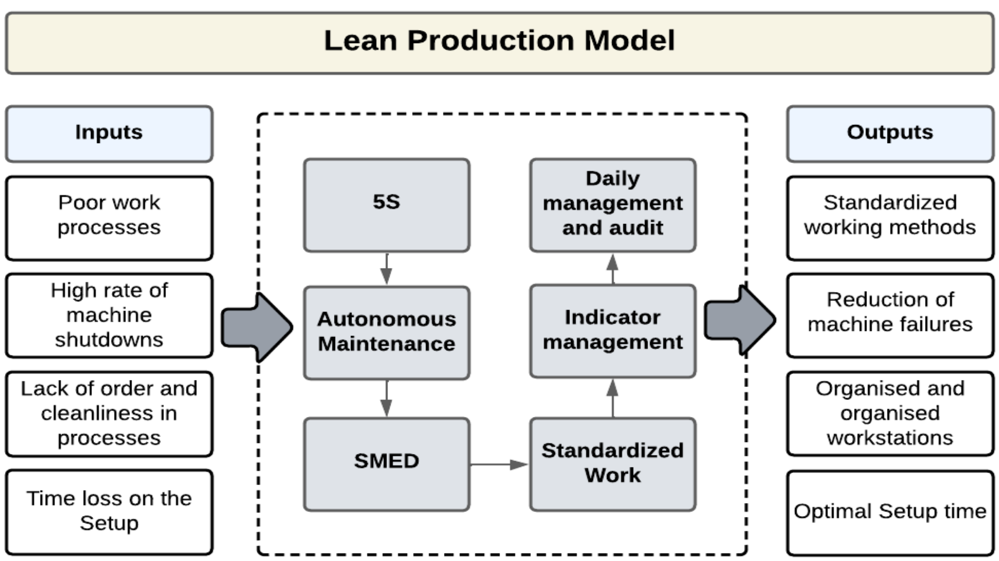

Figure 1. Proposed Model

3.2 Description of the model components

The Lean Production Model presented in the attached figure can be detailed step by step, each addressing specific aspects of process improvement within a production environment. Below, each stage of the model is described along with a bibliographic review that supports the application of these Lean tools. The inputs of the model include the fundamental problems affecting the efficiency and quality of production processes. These inputs are: poor work processes, a high rate of machine shutdowns, lack of order and cleanliness in processes, and time loss in machine setup. Poor work processes refer to the existence of inefficient and disorganized work methods that can cause errors, rework, and loss of time. The high rate of machine shutdowns relates to the frequency with which machines fail or require maintenance, interrupting the production flow. The lack of order and cleanliness in processes indicates a disorganized work environment that can lead to inefficiency and an increased risk of accidents. Finally, time loss in setup refers to the considerable time spent preparing machines for different production processes, reducing the available time for effective production.

The model begins with the implementation of the **5S methodology**, which is a fundamental tool in quality management and workplace organization. The 5S consists of five Japanese principles: Seiri (sorting), Seiton (set in order), Seiso (shine), Seiketsu (standardize), and Shitsuke (sustain). This methodology allows creating and maintaining an orderly, clean, and efficient work environment, facilitating the identification and elimination of waste. The literature shows that the implementation of 5S significantly improves productivity and employee morale (Hirano 1996; Gapp et al. 2008).

The next stage is **Autonomous Maintenance**, which focuses on training operators to perform basic and routine maintenance tasks on the machines they operate. This includes cleaning, lubrication, and minor adjustments. Autonomous Maintenance empowers workers, fosters a sense of responsibility, and helps identify problems before they become major failures (Nakajima 1988). Various studies have demonstrated that the implementation of Autonomous Maintenance significantly reduces machine downtime and improves operational efficiency (Bamber et al.1999).

The **SMED (Single-Minute Exchange of Die) methodology** is crucial for reducing machine setup time. SMED focuses on converting internal setup activities (which require stopping the machine) into external activities (which can be performed while the machine is running) and simplifying all setup activities. Reducing setup time allows for greater production flexibility and reduces batch sizes, which is essential in a Lean production environment (Shingo 1985). Research indicates that the application of SMED can reduce setup times by 50-90% (Cakmakci 2009).

Standardized work is the next phase, which involves documenting and applying the best-known methods to perform a task consistently. This standard serves as the basis for continuous improvements. Standardized work is crucial for maintaining quality and efficiency, as it ensures that all operations are performed uniformly and efficiently (Liker 2004). Studies have shown that standardizing work improves product quality and reduces process variations (Emiliani et al. 2007).

Indicator management is another essential stage of the model. It involves tracking and analyzing production data to identify areas for improvement. Key Performance Indicators (KPIs) help managers make informed decisions and direct continuous improvement efforts. Indicator management allows for constant feedback and a data-driven approach to problem-solving (Kaplan & Norton 1992). The literature supports the idea that effective indicator management improves overall manufacturing performance (Neely et al. 1995).

Finally, **daily management and audits** are essential to maintaining and continuously improving established standards. Regular audits help ensure that procedures are followed and quickly identify deviations, allowing for immediate corrective actions. Daily management provides a structure for ongoing supervision and support of daily operations, fostering a culture of continuous improvement and accountability (Imai 1986). Research shows that effective daily management and audits can lead to sustainable improvements in productivity and quality (Dombrowski & Mielke 2014).

The results of implementing this Lean Production model include standardized working methods, reduction of machine failures, organized workstations, and optimized setup time. These results are consistent with the principles of Lean Manufacturing, which aim to eliminate waste and continuously improve processes (Womack & Jones 1996). The literature has documented numerous cases where the application of Lean tools has led to significant improvements in production efficiency and quality (Shah & Ward 2003).In conclusion, the detailed Lean Production model in the figure provides a structured framework to address common issues in manufacturing processes. By implementing methodologies such as 5S, Autonomous Maintenance, SMED, standardized work, indicator management, and daily audits, organizations can significantly improve operational efficiency, reduce downtime, and increase product quality. The literature review supports the effectiveness of these tools and highlights the importance of a systematic and disciplined approach to achieving sustainable improvements in the production environment.

.

3.3 Model Indicators

To assess the efficacy of the suggested production model, specific indicators were established to oversee and regulate the outcomes of its implementation in the case study.

Operational Efficiency: this indicator measures the ratio of productive time to the total available time, reflecting the effectiveness of resource utilization in producing defect-free goods.

.

$$Operational\ Efficiency = \frac{Productive\ Time}{Total\ available\ time} \times 100 \quad (1)$$

Defective Products Rate: this indicator measures the percentage of defective products in a garment sewing plant, assessing the production process quality. The calculation formula is:

$$Defective\ products\ rate = \frac{Number\ of\ Defective\ Products}{Total\ numbers\ of\ products\ manufactured} \times 100 \quad (2)$$

Cycle time sewing: The indicator measures the total time required to complete one unit from the start to the end of the sewing process. The calculation formula is:

$$\text{Cycle time sewing} = \frac{\text{Total sewing time}}{Number\ of\ units\ produced} \quad (3)$$

Setup time: is the total time spent preparing and adjusting sewing machines before starting garment production. This indicator measures the efficiency in the setup stage and its impact on productivity.

$$\text{Setup time} = \frac{\text{Total setup time}}{Number\ of\ setups} \quad (4)$$

Availability: this indicator measures the effective operational time compared to the total planned production time, reflecting the plant's ability to operate without interruptions.

$$\text{Availability} = \frac{Effective\ operational\ time}{Total\ planed\ time} \quad (5)$$

4. Validation

4.1 Initial Diagnosis

The presented problem tree represents in **Figure 2** a detailed diagnosis of the case study, aimed at identifying the main causes and reasons affecting operational efficiency in the textile sector. The standard operational efficiency, according to Nchala et al. (2022), was 81.93%, while the case study efficiency was 65.98%, highlighting a significant technical gap. This low operational performance resulted in an economic impact of 78,361 PEN per year, equivalent to 8.2% of sales. The analysis identified that 45.56% of the low operational efficiency was due to defective products, primarily caused by operator handling errors in the sewing process (19.88%) and high setup time (13.72%). Additionally, an excess of unplanned stoppages contributed 45.44% to the low efficiency, stemming from technical failures in the machines (13.72%) and high order time, sorting, and cleaning at workstations (11.85%). Finally, 9.00% of the operational inefficiency was attributed to delays in the cutting process, with excessive cutting time. This integrative approach quantitatively and qualitatively identified the main factors contributing to the research problem, providing a solid foundation for developing improvement strategies in the textile sector.

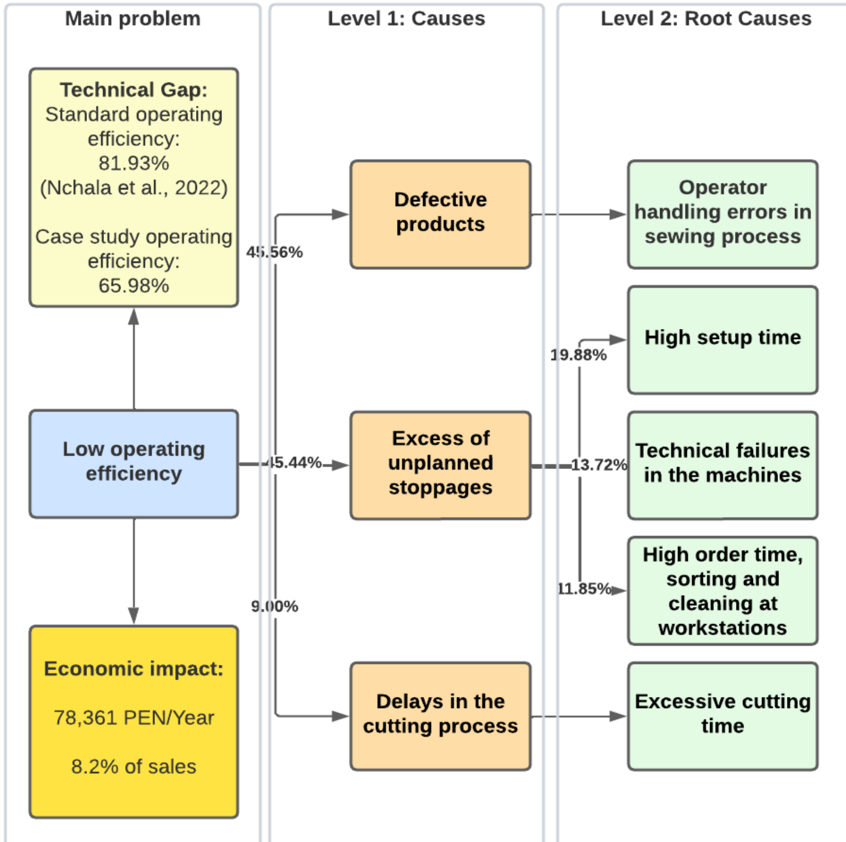

Figure 2. Problem Tree

4.2 Implementation of the 5S methodology

The implementation of the 5S methodology was carried out with the objective of reducing the high times associated with order and cleanliness in the company. The process was developed in six phases, starting with the approval of an implementation plan by management to ensure the company's commitment. The importance of informing the respective areas about the benefits of the tool was highlighted to foster collaboration and integration with the implementation team.

A training program was implemented for the work departments to instruct on the concepts, objectives, and benefits of the 5S. The classification phase (Seiri) included creating a flow of resource classification, dividing items into those that generate value (VA), do not generate value (NVA), and necessary activities that do not add value (NNVA). To prevent the misuse of eliminated resources, a red tag format was used for control. In the order phase (Seiton), the order of the classified resources was established and maintained, defining specific actions for each type of resource. The cleaning phase (Seiso) focused on creating a clear cleaning process and reinforcing the cleaning culture among workers, emphasizing the importance of hygiene for occupational safety, in accordance with Law No. 29783 on Occupational Safety and Health.

The resulting cleaning manual detailed the cleaning activities, responsible parties, equipment, objectives, and cleaning criteria, and a cleaning schedule was structured to be rigorously followed. The standardization phase (Seiketsu) integrated the first three "S" through specific conditions for each work department, including the assignment of responsible parties and activity control. The final phase, discipline (Shitsuke), focused on instilling discipline in the new processes and evaluating the need for corrective or preventive actions. Each phase had its own evaluation and scoring. The results showed a significant improvement in efficiency, reducing the production cycle time by 34%, the inventory time by 14%, and the time in non-valued activities by 32%. **Figure 3** shows the process followed for the implementation of the 5S methodology in the case study.

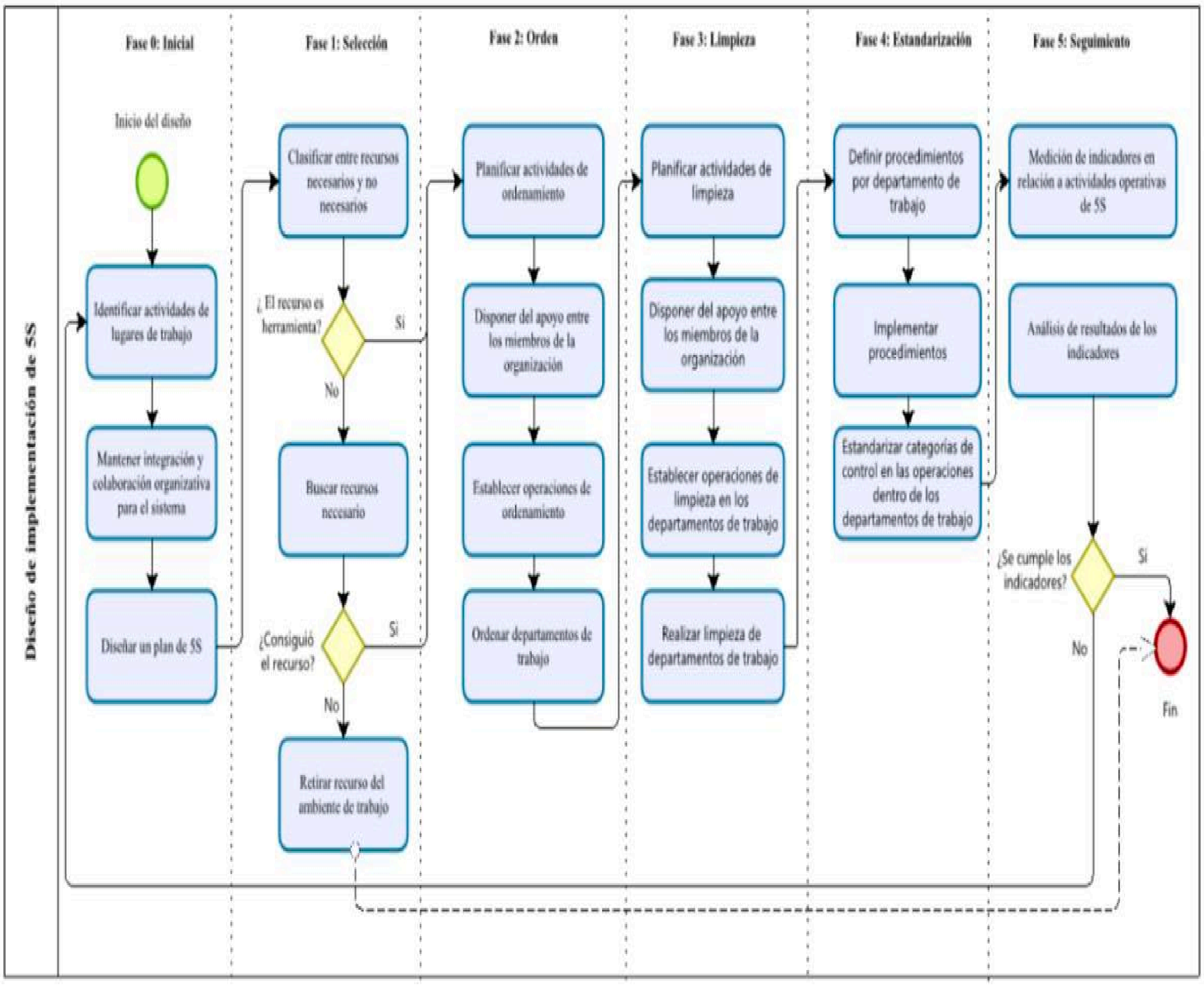

Figure 3. The implementation process of the 5S methodology

Table 1 shows the comparison between planned and actual days spent on tidiness and cleanliness, as well as the impact in minutes. This shows the changes achieved in the company through the implementation of 5S.

4.3 Development and Implementation of TPM (Autonomous Maintenance)

The development and implementation of Autonomous Maintenance (TPM) were executed in five clearly defined phases. Initially, an inspection of all available machinery was carried out, evaluating their functions in the production process, the type and frequency of maintenance received. The company had machines such as the overlock machine and the cutting machine, which were cleaned and lubricated weekly, with the blade changed bimonthly. It was determined that it was necessary to standardize maintenance activities so that they were understandable to all operators. Specific norms and processes for the lubrication and inspection of each machine were established

Table 1. Comparison Days of Order - Classification – Cleaning

Month	**Days of Order and Cleanliness (Program)**	**Days of Order and Cleanliness (Real)**	**Impact in minutesutos**
January	15	24	92.7
February	15	24	92.7
March	8	27	195.7
April	8	24	164.8
May	15	25	103
June	15	25	103
July	14	24	103
August	9	25	164.8
September	10	26	164.8
October	8	27	195.7
November	14	25	113.3
December	11	25	144.2
Total	**142**	**301**	**1637.7**

The next phase involved eliminating sources of contamination to keep the machinery in optimal condition, emphasizing order and cleanliness. A monthly maintenance schedule was established, detailing cleaning and lubrication activities, and blade changes in even months. This helped reduce technical failures, such as blade changes, which in 2021 represented an impact of 1,896.1 minutes in production. During the inspection and monitoring phase, the ANSI TAPPI TIP 0305-34 standard was applied to create checklists for maintenance, allowing workers to perform regular inspections and maintain detailed records. The maintenance control sheet used included details of the machine's condition and photographic evidence.

The final phase focused on the standardization and self-control of maintenance. The operators were instructed to ensure they had the knowledge and skills necessary to perform autonomous maintenance effectively. A training format was implemented to record the training sessions, ensuring that the instructor was qualified to provide such training.
Thanks to these measures, there was a significant improvement in productive efficiency. For example, the impact of technical machinery failures decreased, increasing machine availability by 12.98%. Additionally, downtime was reduced, contributing to greater stability and continuity in the production process. Figure 4 shows the process followed for the implementation of the Autonomous Maintenance in the case study.

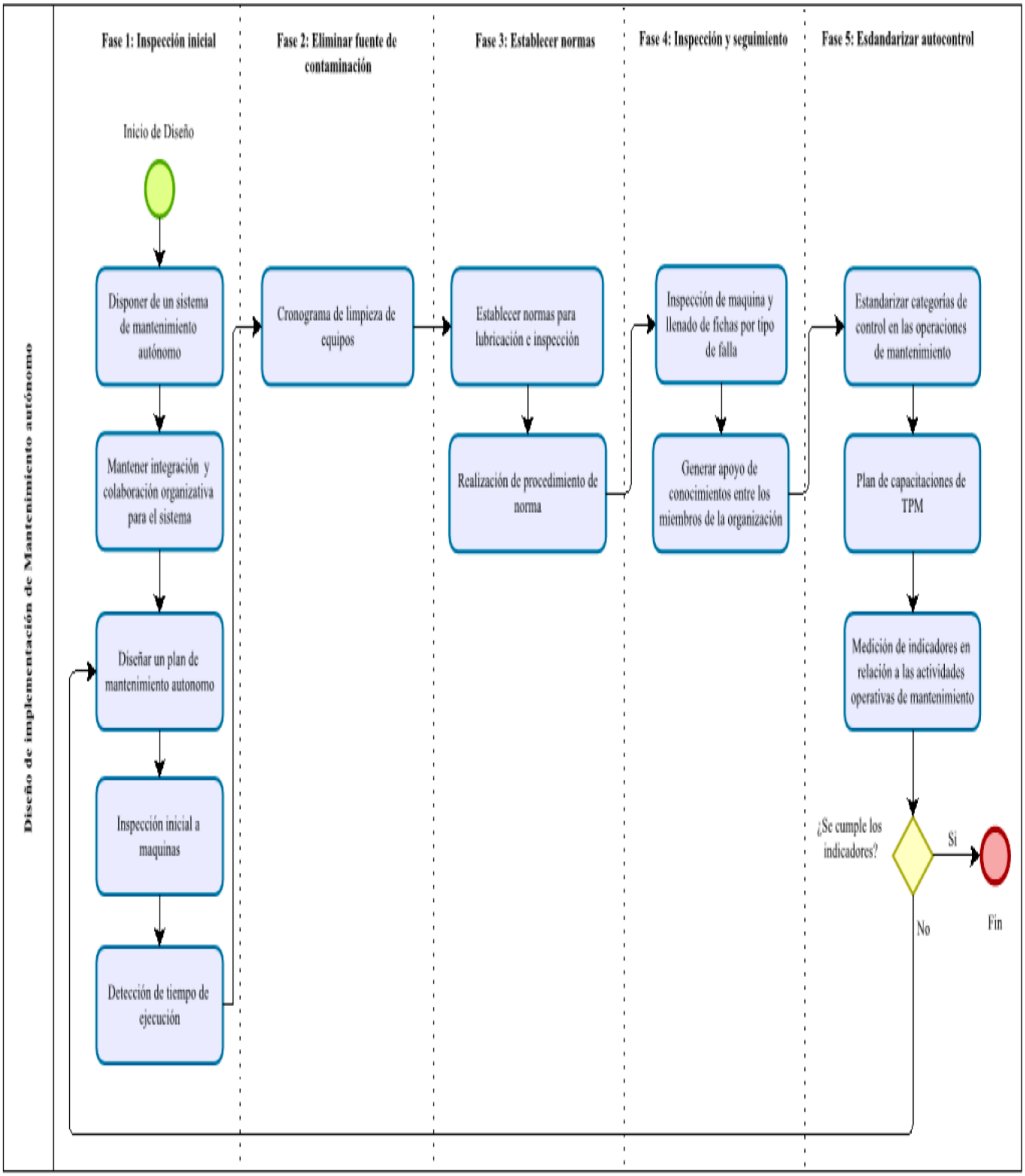

Figure 4. Process for the implementation of the Autonomous Maintenance

Figure 5 shows an equipment inspection sheet used for maintenance control. It includes details such as the machine name, operator, model, brand, and current condition. There are also sections for photos and comments, along with a space for the operator's signature.

Inspección del equipo		Nro de ficha	
		Fecha	
Máquina		Motor	
Operario		Velocidad de trabajo	
Modelo		Nivel de seguridad	
Marca		Nivel de estado	
Estado Actual			
Fotos		Comentarios	
Firma del operario			

Figure 5. Maintenance Control Sheet for Machinery Inspection

4.4 Development of SMED implementation

The development of the SMED implementation in the textile company was carried out with the objective of optimizing machine setup times, reducing downtime, and improving production efficiency. Initially, it was identified that the overlock sewing machine involved the most operations in the basic polo shirt manufacturing process. In this phase, it was recognized that the process included shoulder joining, sleeve attachment, and side seam closing, making it crucial for the garment preparation. The first phase consisted of separating internal and external activities, determining the preparation time associated with using the overlock sewing machine. For example, internal activities such as needle changes, which took 2.90 minutes, and needle verification, which required 0.70 minutes, were identified. In contrast, external activities such as thread selection, which took 0.60 minutes, and thread insertion, which required 1.80 minutes, were considered for conversion to external tasks to minimize machine downtime.

In the second phase, it was proposed that the production assistant support certain preparation activities, such as selecting and placing the thread in the overlock sewing machine before the main operation. This support would allow for a reduction in total setup time, optimizing resource utilization and improving productivity.The detailed analysis and implementation of these phases allowed for a significant reduction in machine setup times. It is estimated that the proper implementation of SMED could decrease setup time by 27.26%, contributing to greater machine availability and, consequently, lower production costs. The effectiveness of this methodology lies in the conversion of internal activities to external ones, ensuring that preparation time does not exceed ten minutes, aligning with the company's efficiency and productivity goals.

This implementation not only optimized setup times but also demonstrated an improvement in staff coordination and participation, which is crucial for the ongoing success of SMED in complex production processes. Figure 6 shows the process followed for the implementation of the SMED Methodology in the case study.

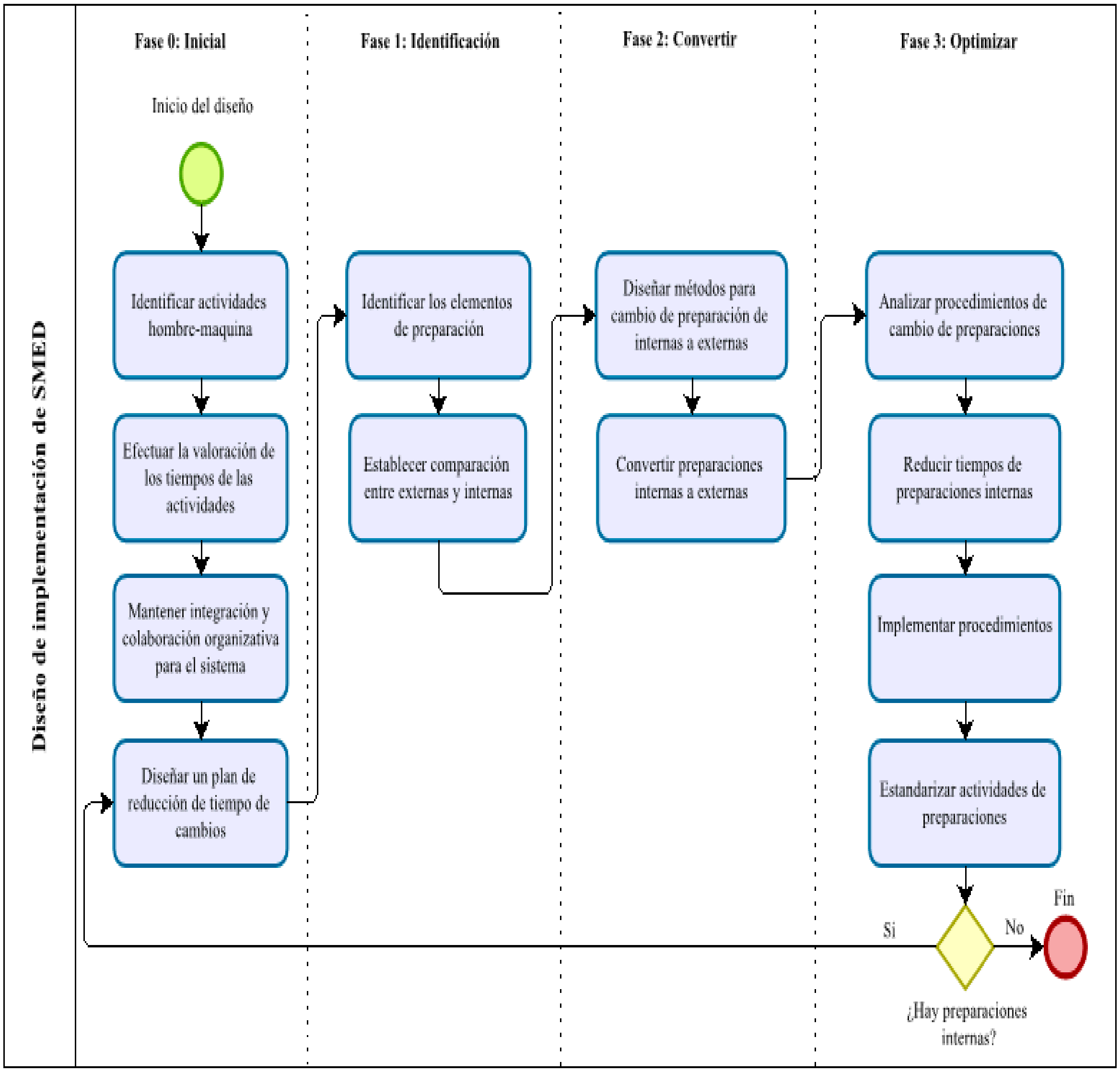

Figure 6. Process for the implementation of the SMED methodology

Table 2 below shows the separation between internal and external activities for the overlocking machine. Two activities were classified as external: "cleaning leftovers" and "checking leftovers", with durations of 0.30 minutes each. These activities are carried out by the sewing operator.

Table 2. Classification between internal and external activities

Machine	Responsible	Activity	Internal	External	Time (min)
Overlock machine	sewing machine operator	Preparation of the piece assembly	X		0.7
	sewing machine operator	Speed control of the sewing process	X		0.4
	sewing machine operator	Change of foot Think of them	X		0.5
	sewing machine operator	Needle exchange	X		2.9
	sewing machine operator	Check needle	X		0.7
	sewing machine operator	Thread selection	X		0.6
	sewing machine operator	Add thread	X		1.8
	sewing machine operator	Tension of the thread and needle	X		0.5
	sewing machine operator	Tap coil (winding)	X		0.8
	sewing machine operator	Tap coil (threaded or threaded)	X		1.1
	sewing machine operator	Check plate to arise	X		0.4
	sewing machine operator	Selection of the stitch patterns	X		0.4
	sewing machine operator	Clean up leftovers		X	0.3
	sewing machine operator	Check for leftovers		X	0.3
	sewing machine operator	Sew	X		0.6
Total			**13**	**2**	**12**

Finally, table 3 shows that it was possible to optimize up to 4 minutes in relation to the overlocking machine.

Table 3. Optimization of preparation time with the proposed method

Machine	Activity	Action	Current time of preparing	Proposed time preparin g
Overlock machine	Preparation of the piece assembly	Activity is maintained	0.7	0.7
	Speed control of the sewing process	Activity is maintained	0.4	0.4
	Change of foot Think of them	Production assistant support in the process of change	0.5	0.0
	Needle exchange	The machine operator can go checking the	2.9	2.4
	Check needle	stability and tension of the needle during the change	0.7	
	Thread selection	The machine operator go by laying the thread and	0.6	1.55
	Add thread	add it directly	1.8	
	Tension of the thread and needle	Activity is removed	0.5	0.0
	Tap coil (winding)	Production assistant support during winding	0.8	0.4
	Tap coil (threaded or threaded)	Production assistant support during threading	1.1	0.55
	Check plate to arise	Activity is maintained	0.4	0.4
	Selection of the stitch patterns	Activity is maintained	0.4	0.4
	Clean up leftovers	Activity is maintained	0.3	0.3
	Check for leftovers	Activity is maintained	0.3	0.3
	Sew	Activity is maintained	0.6	0.6
Total			**12**	**8.00**

4.5 Development of the Standardized Work implementation

The implementation of work standardization in the garment manufacturing company addressed the root cause of operator handling errors during the production process. According to the study by Realyvásquez et al. (2019), work standardization reduces waste by sequentially defining efficient methods and tasks for each process and operator. The implemented model consisted of six phases that optimized various activities at the workstation.

Initially, all operations at the workstation were globally analyzed using an activity diagram that showed 23 activities, including 22 operations and 1 inspection, with a total time of 9.30 minutes. Subsequently, activities were classified based on whether they added value (VA) or not (NVA), for both the worker and the machinery. Current and proposed times were established for each activity, resulting in a significant reduction in the total preparation time from 12.00 to 8.00 minutes.

Among the highlighted improvements, the needle change time was reduced from 2.90 minutes to a shorter time activity through optimization and the support of a production assistant. The selection and addition of thread, which initially took 0.60 and 1.80 minutes respectively, were also reduced by implementing a more efficient process. Similarly, the activity of threading the bobbin, which took 1.10 minutes, was optimized to 0.55 minutes.

DIAGRAMA DE ANÁLISIS DE PROCESO					
CURSOGRAMA ANALITICO	OPERARIO/ ~~MATERIAL/ EQUIPO~~				
DIAGRAMA N° 1 **Hoja N° 1 de 1**	**R E S U M E N**				
PRODUCTO/MATERIAL/HOMBRE: Polo de algodón	**ACTIVIDAD**		**ACTUAL**	**PROPUES**	**ECONOMÍA**
ACTIVIDAD: Confección	OPERACIÓN	●	13		
	TRANSPORTE	➡	0		
MÉTODO: ACTUAL/~~PROPUESTO~~	ESPERA	D	0		
LUGAR: Confecciones SMAS	INSPECCIÓN	■	1		
OPERARIO (S) : Juana Vargas CÓDIGO:	ALMACENAMIENTO	▼	0		
ELABORADO POR: Barrientos FECHA: 10/06/2022	DISTANCIA (metros)				
APROBADO POR: FECHA:	TIEMPO (hr-hombre)				

DESCRIPCIÓN	**DISTANCIA (metros)**	**TIEMPO (min)**	**SÍMBOLO** ●	■	➡	D	▼	**OBSERVACIONES**
1. Coger la parte delantera, parte espalda y pasar por máquina		0.61	X					Máquina remalladora
2. Coser cuellos		0.64	X					Máquina collaretera
3. Coger una manga derecha e izquierda		0.19	X					
4. Remallar los contornos		0.76	X					Máquina remalladora
5. Coger otra manga derecha e izquierda		0.24	X					
6. Remallar los contornos		0.78	X					Máquina remalladora
7. Coser las mangas uniendo delantera y espalda		0.19	X					Máquina remalladora
8. Hacer primer dobles de mangas y pasar por la máquina		0.54	X					Máquina recubridora
9. Hacer segundo dobles de mangas y pasar por la máquina		0.55	X					Máquina recubridora
10. Hacer dobles de polo parte baja y pasar por máquina		0.61	X					Máquina recubridora
11. Coger etiqueta y coser al polo		0.35	X					Máquina remalladora
12. Revisar costuras		0.78		X				
13. Coger tijeras y cortar hilos que sobran		0.53	X					
14. Colocar al lado de la mesa		0.14	X					
TOTAL		6.91	13	1	0	0	0	

Figure 7. Improvement Proposal - Process Activity Diagram (PAD) of the clothing manufacturing process

The analysis and implementation of the model resulted in a significant improvement in the efficiency of the sewing process. Work standardization not only reduced the preparation time from 12.00 to 8.00 minutes but also improved the quality of the work performed, decreasing handling errors and increasing operator productivity. This sequential and detailed approach allowed for a more streamlined and controlled process, reducing non-productive times and optimizing the use of available resources. Figure 7 shows that by eliminating certain activities, we eliminated the confection time from 9.30 minutes to 6.91 minutes (a reduction of approximately 26%).

5. Results

After the implementation of the pilots in the case study for 6 months is shown in table 4 the indicators comparing the "As-Is" and "To-Be" states of operational efficiency, defective product rate, cycle time seam and set-up time. It shows significant improvements, such as a 32.01% increase in operational efficiency and a 27.26% reduction in set-up time.

Table 4. Results of validation of the proposed model

Indicator	As-Is	To-Be	Results	Variation (%)
Operational Efficiency	64.27%	85%	84.84%	**32.01%**
Defective Products Rate	11.81%	7%	8.29%	**-29.81%**
Cycle time sewing	9.1	7	7.9	**-13.19%**
Setup time	11.59	8	8.43	**-27.26%**
Availability	78.92%	95%	91.90%	**16.45%**

6. Conclusions

The main findings of this study revealed that the implementation of the proposed model based on Lean Manufacturing and Total Productive Maintenance (TPM) resulted in a significant improvement in operational efficiency in the analyzed textile company. Productive efficiency increased from 64.27% to 84.84%, and the defective product rate decreased from 11.81% to 8.29%. Additionally, the average sewing cycle time decreased from 9.1 to 7.9 minutes, and machine setup time was reduced from 11.59 to 8.43 minutes. These results were validated through simulations and pilot tests, demonstrating the model's effectiveness in improving key performance indicators in textile production.
The importance of this research lies in its ability to address and resolve critical issues in small and medium-sized enterprises (SMEs) in the textile sector, which is vital to the Peruvian economy. By improving productive efficiency and reducing defects in the production process, the research not only contributes to the sustainability and competitiveness of these companies but also promotes more efficient and sustainable production practices, benefiting both the industry and the local economy.

Regarding contributions to the field of study, this work fills a gap in the literature on the application of Lean Manufacturing and TPM tools in textile SMEs. The integration of methodologies such as 5S, SMED, and Autonomous Maintenance not only optimizes production processes but also empowers workers through standardization and active participation in machine maintenance. This holistic and participatory approach has proven effective in improving the efficiency and quality of the production process, setting a precedent for future research in the sector.

Final observations suggest that, although the proposed model has proven effective, additional studies are recommended to explore the integration of advanced technologies such as Industry 4.0 and artificial intelligence in textile production processes. These technologies have the potential to take optimization and efficiency to new levels, providing textile SMEs with even more powerful tools to compete in the global market. Additionally, continuous evaluation and periodic adjustments of the implemented model are suggested to adapt to market changes and the specific needs of each company. In conclusion, this research underscores the importance of adopting efficient and standardized production practices in the textile sector. It invites researchers and professionals to continue exploring and refining these methodologies, fostering a culture of continuous improvement and sustainability in the textile industry. The application of these approaches not only enhances productivity and quality but also contributes to the economic and social development of the communities where these companies operate.

References

Ali, Z., Predicting SMEs performance through green supply chain practices: a mediation model link of business process performance. Asia Pacific Journal of Marketing and Logistics, 35(2), 432-450,2022. https://doi.org/10.1108/apjml-05-2021-0296

Bamber, C. J., Sharp, J. M., & Hides, M. T., Factors affecting successful implementation of total productive maintenance. Journal of Quality in Maintenance Engineering, 5(3), 162-181,1999. https://doi.org/10.1108/13552519910282747

Bandara, R. , Impact of debt and equity financing on firm performance during COVID-19 pandemic in Sri Lanka empirical study in the apparel and textile industry in the western province. Journal of Accountancy & Finance, 9(2), 342-367, 2023. https://doi.org/10.57075/jaf922205

Boschmeier, E., Ipsmiller, W., & Bartl, A., Market assessment to improve fibre recycling within the EU textile sector. Waste Management & Research the Journal for a Sustainable Circular Economy, 42(2), 135-145,2-2023. https://doi.org/10.1177/0734242x231178222

Cakmakci, M., Process improvement: Performance analysis of the setup time reduction–SMED in the automobile industry. The International Journal of Advanced Manufacturing Technology, 41(1-2), 168-179,2009. https://doi.org/10.1007/s00170-008-1434-4

Demirtaş, E., Gultekin, O., & Uskup, C., A case study for surgical mask production during the COVID-19 pandemic: continuous improvement with kaizen and 5s applications. International Journal of Lean Six Sigma, 14(3), 679-703,2022. https://doi.org/10.1108/ijlss-02-2022-0025

DIVRIK, B. and Baykal, E. (2024). Relation of digitalization and internationalization for smes; evidence from turkish textile and clothing industry. Journal of Global Strategic Management. https://doi.org/10.20460/jgsm.2023.318

Dombrowski, U., & Mielke, T. (2014). Lean leadership–15 rules for a sustainable lean implementation. Procedia CIRP, 17, 565-570,2024. https://doi.org/10.1016/j.procir.2014.01.146

Emiliani, M. L., Stec, D. J., Grasso, L., & Stodder, J. (2007). Better thinking, better results: Case study and analysis of an enterprise-wide lean transformation. Second Edition. Center for Lean Business Management.

Fathi, M., Sobhani, S., Maleki, M., & Jandaghi, G. (2021). Future study of textile industry in iran using the micmac and soft operational research methods. Foresight, 23(4), 439-456. https://doi.org/10.1108/fs-02-2020-0017

Forno, A., Bataglini, W., Steffens, F., & Souza, A., Industry 4.0 in textile and apparel sector: a systematic literature review. Research Journal of Textile and Apparel, 27(1), 95-117,2021. https://doi.org/10.1108/rjta-08-2021-0106

Gapp, R., Fisher, R., & Kobayashi, K, Implementing 5S within a Japanese context: An integrated management system. Management Decision, 46(4), 565-579,2008. https://doi.org/10.1108/00251740810865067

Hirano, H. (1996). 5 Pillars of the Visual Workplace: The Sourcebook for 5S Implementation. Productivity Press.

Hrouga, M. and Michel, S. , Towards a new supply chain manager dashboard under circular economy constraints: a case study on france textile and clothing industry. Business Strategy and the Environment, 32(8), 6074-6093, 2023. https://doi.org/10.1002/bse.3473

Imai, M. (1986). Kaizen: The Key to Japan's Competitive Success. Random House Business Division.

Juanga-Labayen, J., Labayen, I., & Yuan, Q. (2022). A review on textile recycling practices and challenges. Textiles, 2(1), 174-188. https://doi.org/10.3390/textiles2010010

Kaplan, R. S., & Norton, D. P. , The balanced scorecard: Measures that drive performance. Harvard Business Review, 70(1), 71-79,1992.

Kose, Y., Muftuoglu, S., Çevikcan, E., & Durmuşoğlu, M., Axiomatic design for lean autonomous maintenance system: an application from textile industry. International Journal of Lean Six Sigma, 14(3), 555-587,2022. https://doi.org/10.1108/ijlss-01-2022-0020

Lei, L., Shi, S., Wang, D., Meng, S., Dai, J., Fu, S., … & Hu, J., Recent advances in thermoregulatory clothing: materials, mechanisms, and perspectives. Acs Nano, 17(3), 1803-1830,2023. https://doi.org/10.1021/acsnano.2c10279

Liker, J. K. (2004). The Toyota Way: 14 Management Principles from the World's Greatest Manufacturer. McGraw-Hill.

Lin, R., Kim, H., Achavananthadith, S., Xiong, Z., Lee, J., Kong, Y., … & Ho, J. , Digitally-embroidered liquid metal electronic textiles for wearable wireless systems. Nature Communications, 13(1),2022. https://doi.org/10.1038/s41467-022-29859-4

Nakajima, S. (1988). Introduction to TPM: Total Productive Maintenance. Productivity Press.

Neely, A., Gregory, M., & Platts, K., Performance measurement system design: A literature review and research agenda. International Journal of Operations & Production Management, 15(4), 80-116,1995. https://doi.org/10.1108/01443579510083622
Palacios-Mateo, C., Meer, Y., & Seide, G., Analysis of the polyester clothing value chain to identify key intervention points for sustainability. Environmental Sciences Europe, 33(1), 2021. https://doi.org/10.1186/s12302-020-00447-x
Sarasi, V., Primiana, I., Harsanto, B., & Satyakti, Y. (2023). Sustainable supply chain of Indonesia's textile & apparel industry: opportunities and challenges. Research Journal of Textile and Apparel. https://doi.org/10.1108/rjta-08-2022-0091
Shah, R., & Ward, P. T., Lean manufacturing: Context, practice bundles, and performance. Journal of Operations Management, 21(2), 129-149, 2003. https://doi.org/10.1016/S0272-6963(02)00108-0
Shingo, S. (1985). A Revolution in Manufacturing: The SMED System. Productivity Press.
Singhal, N., Stakeholders sustainable development goals (sdgs) prioritization. Business Strategy & Development, 6(4), 986-990, 2023. https://doi.org/10.1002/bsd2.292
Soares, R.,Impact of research and development expenses on the profitability of assets: the case of textile and clothing industry in portugal. Problems and Perspectives in Management, 22(1), 702-715,2024. https://doi.org/10.21511/ppm.22(1).2024.55
Stefan, D., Bosomoiu, M., & Stefan, M., Methods for natural and synthetic polymers recovery from textile waste. Polymers, 14(19), 3939, 2022. https://doi.org/10.3390/polym14193939
Ta, A., Aarikka-Stenroos, L., & Litovuo, L. , Customer experience in circular economy: experiential dimensions among consumers of reused and recycled clothes. Sustainability, 14(1), 509,2022. https://doi.org/10.3390/su14010509
Tian, B., Fang, Y., Liang, J., Zheng, K., Guo, P., Zhang, X., … & Wu, W. , Fully printed stretchable and multifunctional e-textiles for aesthetic wearable electronic systems. Small, 18(13), 2022. https://doi.org/10.1002/smll.202107298
Velmurugan, K., Venkumar, P., & Sudhakara, P. , Sme 4.0: machine learning framework for real-time machine health monitoring system. Journal of Physics Conference Series, 1911(1), 012026, 2021. https://doi.org/10.1088/1742-6596/1911/1/012026
Verma, A. , Advancements in enhancing antibacterial properties of cotton fabric through chitosan and nanoparticles. Chemistryselect, 8(44), 2023. https://doi.org/10.1002/slct.202303215
Womack, J. P., & Jones, D. T. (1996). Lean Thinking: Banish Waste and Create Wealth in Your Corporation. Simon & Schuster.
Zaman, S., Tao, X., Cochrane, C., & Končar, V., Smart e-textile systems: a review for healthcare applications. Electronics, 11(1), 99,2021. https://doi.org/10.3390/electronics11010099

Biography

Ignacio Herrera-Barreda holds a bachelor's degree in industrial engineering with expertise in logistics, commercial management, and strategic planning. With a strong background in supply chain optimization and client relationship management, he has experience in leading retail operations and digital sales strategies. He is currently working as a Commercial Supervisor, focusing on enhancing sales performance and customer engagement through innovative approaches.