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Original Article

Enhancing Machine Availability in Plastic SMEs through Lean and TPM: Evidence from a Peruvian Case Study

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Abstract *- The plastic manufacturing sector in Peru faces significant challenges related to machine downtime and prolonged set-up times, which limit productivity and increase operational costs. Previous studies have highlighted the benefits of Lean Manufacturing and Total Productive Maintenance (TPM) for improving equipment efficiency, yet the integration of these methodologies in SMEs remains limited. This research addressed these challenges by developing a production model integrating Lean Manufacturing tools, such as SMED and Standardized Work, with TPM practices, specifically Autonomous and Planned Maintenance. The proposed model was validated in a Peruvian SME within the plastic sector, resulting in a 9.25% increase in machine availability and a 30.89% reduction in mold changeover time. These improvements enhanced production capacity and process stability, demonstrating the model's effectiveness in reducing unplanned stoppages. This study contributes to the body of knowledge by providing a replicable framework for optimizing manufacturing processes in plastic SMEs, suggesting further exploration of its scalability in other industrial contexts.*

Keywords *- Lean Manufacturing, Total Productive Maintenance, Machine Availability, Plastics SMEs, Operation Efficiency.*

1. Introduction

The plastic industry is one of the most important industries in the world. In 2019, the world's plastic production reached 368 million tons, fueled by the packaging, construction, and automotive industries [1]. In Latin America, Small And Medium-sized Enterprises (SMEs) make up a large part of this industry and have to deal with a lack of resources and technology [2]. In Peru, the plastics sector accounts for around 4% of the Industrial GDP and provides more than 200 thousand jobs, which makes it important from both economic and social standpoints [3]. These small and medium-sized enterprises constitute 99% of the productive units in the region and account for 75% of formal employment [4].

There are noteworthy operational challenges encountered by Small- and Medium-sized Enterprises (SMEs) in the plastics industry, including low machinery availability and lengthy set-up times. Studies show that unanticipated downtime and mold changeover are the largest productivity bottlenecks in a given operation, impeding efficiency and driving up expenses [5]. As an illustration, one company in Peru's plastics sector used Lean tools, specifically SMED and TPM, and was able to cut changeover times by 20%, which greatly enhanced productivity [6]. Such operational challenges directly erode the competitiveness of SMEs by causing cost overruns and capping the adequate installed capacity [7]. Implementing Lean Manufacturing and TPM practices has proven successful in overcoming these issues. As one of the Lean tools, SMED improves flexibility by lowering production stage set-up time and enabling quicker production shifts [8]. On the other hand, TPM is centered on maximizing the efficiency of a given piece of equipment utilizing self and scheduled maintenance, resulting in lesser downtimes and better machine availability [9]. Combining these two approaches leads to remarkable gains in operational efficiency for SMEs within the plastics subsector [10]. However, a critical gap in the current literature is the lack of integrated models that simultaneously implement Lean Manufacturing and TPM tools explicitly tailored for SMEs in the plastic sector. Most studies apply these methodologies in isolation, without addressing their synergistic potential or adapting them to the constraints of SMEs, such as limited technical personnel and budget. This research addresses this gap by designing and validating an integrated model that simultaneously applies SMED and Standardized Work (from Lean) and Autonomous and Planned Maintenance (from TPM) in a Peruvian plastic SME context, focusing on increasing machine availability and reducing changeover time.

2. Literature Review

2.1. Total Productive Maintenance (TPM) in Plastic Sector SMEs

TPM focuses on eliminating production inefficiencies and optimizing equipment effectiveness. It has been successfully implemented in SMEs within the plastic sector. For example, as noted in [11], Feng and Xiang realized marked gains in production efficiency after applying TPM in one of the manufacturing companies. Abad-Mendoza et al. worked on increasing the machine utilization factor in a plastic sector SME by applying a model based on Lean and TPM principles [12]. Quiroz-Flores and Vega-Alvites reported an increase in OEE in a plastics company after implementing a Lean model incorporating TPM [13] as explained by Mujica-Suarez et al., a combination of SMED and the application of some TPM pillars led to increased productivity in a plastic injection company [14].

2.2. Autonomous Maintenance: Empowering the Operator in TPM

The first TPM pillar is autonomous maintenance, which allocates basic maintenance responsibilities to operators to keep equipment functioning at peak conditions. Sundararajan and Terkar focused on the successful implementation of Lean Manufacturing in SMEs and noted the role of autonomous maintenance [15]. Malpartida and Tarmeño reviewed case studies on the application of Lean Manufacturing in SMEs and highlighted the importance of autonomous maintenance [16]. Implementing 5S in the plastic bag manufacturing industry enhanced operational efficiency [17]. A Lean-TPM model was suggested to enhance the effectiveness and improvement of quality control in SMEs within the plastic industry [18].

2.3. Scheduled Maintenance: Preventing Failures through Scheduling

Another key pillar of TPM is planned maintenance, which focuses on preemptive action and scheduling maintenance activities to intervene proactively before failures happen. Kar reported that machine uptime in a tyre manufacturing company increased with the implementation of TPM planned maintenance [19]. In the plastic industry SMEs, scheduled maintenance is aligned with production timelines, conserving resources and minimizing unplanned downtime [20]. The use of TPM in one manufacturing company resulted in enhanced equipment productivity [21]. An integrated model of Lean and TPM was designed to improve machine uptime in one of the SMEs in the plastic industry [22].

2.4. SMED Methodology: Changeover Time Reduction

Set-up time is a secondary focus of the SMED methodology. This practice minimises downtime in the plastic sector, where molds are frequently altered. In one study on a plastic bag manufacturing company, SMED practices automated mold alterations, which cut changeover times significantly [23]. Another study regarding operational efficiency claimed Lean Manufacturing practices through automation accelerated productivity, confirming the hypothesis [24]. Research indicated that plastic manufacturing flexibility was enhanced dramatically with the use of SMED techniques [25]. The proposal aimed to increase equipment effectiveness in a plastics company using an operations management framework integrated with 5S, TPM, and SMED methodologies [26].

2.5. Standardized Work: The Backbone of Continuous Improvement

Standardized work is the critical structure of Lean Manufacturing regarding constant refinement. Its defining criterion captures the ideal technique for accomplishing any task by defining the actions and fixed times required to complete each step. Standardized work benefits have recorded improvements on the assembly line, proving the model is accurate [27]. In step 4 of Lean Manufacturing, standardization is paramount to safeguard enhancements from reversal [28]. Recurrences and repetitions yield the same results, indicating that losing progress is profoundly discouraged [29]. Results confirm that stagnation is fundamentally unavoidable unless active efforts are taken towards solving the issue [30].

3. Contribution

3.1. Proposed Model

The novelty of this study lies in developing a fully integrated production model that merges key Lean and TPM tools and validates their implementation in a real SME environment. Unlike previous works that analyse these methodologies separately or only theoretically, this research provides empirical evidence of how their integration can effectively reduce machine downtime and changeover times. For instance, while studies such as Mujica-Suarez et al. (2023) and Abad-Mendoza et al. (2024) discuss TPM or SMED individually, this work proposes a cohesive framework that leverages both approaches simultaneously, tailored to the needs and limitations of plastic SMEs in Peru. The significant improvements in availability (+9.25%) and Mold change over time (–30.89%) surpass the performance gains reported in similar stand-alone applications.

Figure 1 presents the proposed production model, which was designed for an SME in the plastic sector to increase the availability of machines on the production line through the integration of Lean Manufacturing principles and Total Productive Maintenance (TPM). This approach was based on two key pillars of TPM: Autonomous Maintenance and Planned Maintenance. Autonomous Maintenance empowered operators to take on basic maintenance responsibilities, thus reducing premature equipment wear and enhancing responsiveness to minor failures. Meanwhile, Planned Maintenance strategically scheduled technical interventions to mitigate unexpected stoppages, ensuring continuous and stable machine operation. Complementarily, Lean tools such as SMED (Single Minute Exchange of Die) and Standardized Work were implemented to minimize changeover times and homogenize operational tasks, respectively. SMED significantly reduced adjustment times in the plastic transformation processes, facilitating greater flexibility in response to production variations. In parallel, Standardized

Work contributed to establishing optimal work sequences, ensuring consistency in execution and reducing operational variability. Together, these practices promoted a culture of continuous improvement, increasing the operational availability of equipment and optimizing the production flow in the SME within the plastic sector, effectively aligning resources to meet demand with high standards of quality and efficiency.

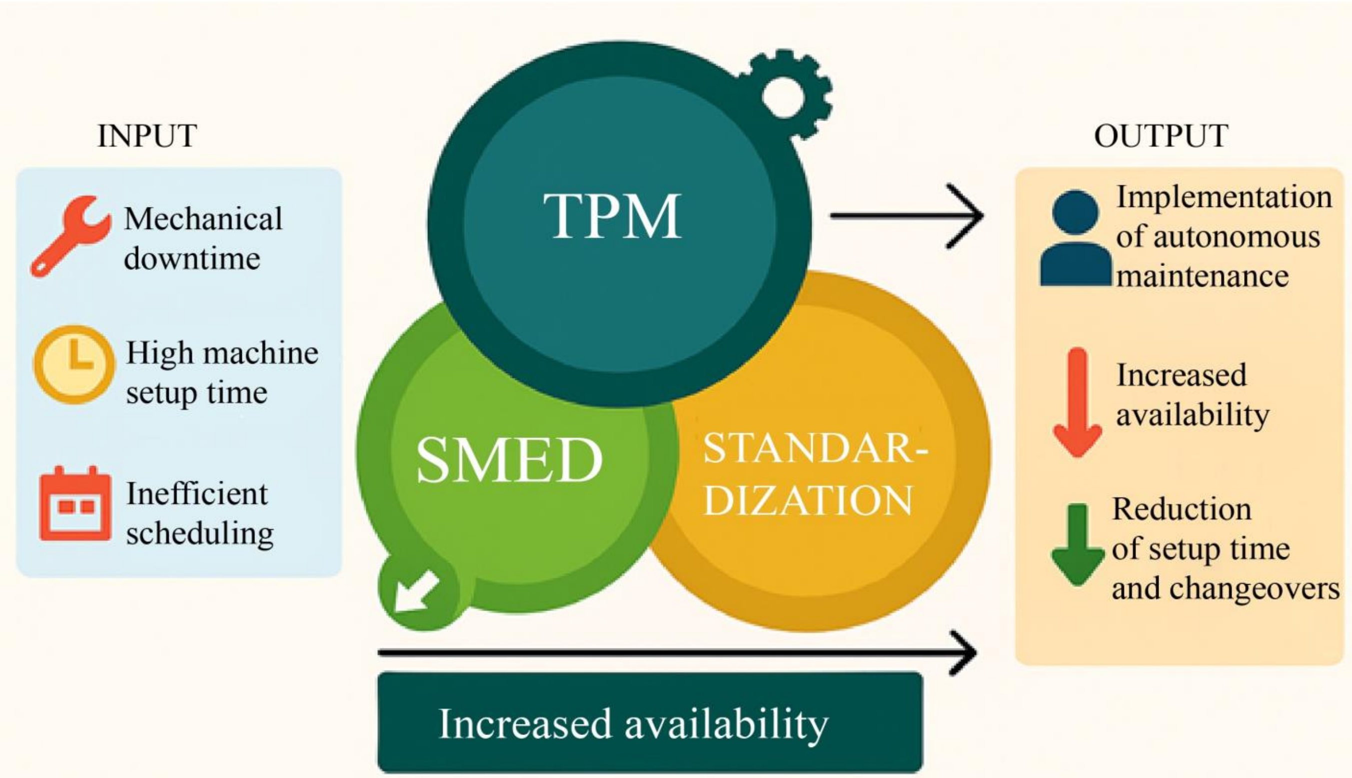

Fig. 1 Proposed model

3.2. Model Components

The resulting production model for this specific case study serves as a method to increase machine uptime for an SME operating within the plastic sector. It stems from Lean Manufacturing and Total Productive Maintenance (TPM). It uses Autonomous Maintenance, Planned Maintenance, SMED (Single Minute Exchange of Die), and Standardized Work as its foundational pillars. These concepts are designed to mitigate stubborn operational issues such as unplanned downtimes, excessive changeover times, and non-uniform task performance among workers. Implementing these methodologies seeks enhanced equipment productivity, consistency in production processes, and improved overall operational effectiveness and dependability of manufacturing systems. This holistic framework estimates adherence to international industrial engineering standards and adds value to existing theories and frameworks to provide a customizable guide for plastics SMEs. Below, we present a detailed description of each model component.

3.2.1. Autonomous Maintenance

Autonomous Maintenance is the defined area of self-directed actions within the maintenance systems framework, where operators are proactive during machine upkeep. This phase deals with assigning specific maintenance functions to machine operators so that they become more responsible and conscious of the equipment's state. Operators undertake routine inspections, lubrication, tightening of parts, and other minor adjustments, which aggregate to a reduction of sudden failures. This approach reduces the need for highly skilled maintenance staff to perform standard maintenance procedures, thus slowing down the response time and increasing the chances of dealing with bigger problems than what exists. Moreover, Autonomous Maintenance actively motivates retraining maintenance operators to better equip them with the necessary tools to diagnose potential signs of faults early on. This approach prolongs the life cycle of assets while fostering responsibility and a culture of self-improvement in the production environment. The adoption of Autonomous Maintenance (AM) in the production line of an SME progresses step by step. To tackle the fundamental gaps, operators are trained to comprehend the associated workflows and weaknesses within the systems. This training encompasses workshops that emphasize the detection of erosion patterns, lubrication to appropriate levels, and tightening mechanical parts. Post-training, operators are given checklists that are repeated daily and are of rudimentary to mid-level managing tasks so that all machines are taken care of daily. All these procedures capture data so that a timeline of machines' conditions can be built to facilitate predictive maintenance. Also, periodic reviews are implemented to measure the impact of AM, which fosters agility in the processes through continual refinement.

As a result of following this approach, in addition to improved accessibility, the reduction of unplanned halts is observed. Along with maintenance competence, the shift in attitude also develops a feeling of guardianship and dedication towards the equipment, which raises their tuning to the actual workings.

3.2.2. Scheduled Maintenance

The second essential part of the proposed production model is Scheduled Maintenance, which Primary Maintenance attempts to support by focusing on its suggestive and preventive functions. This phase is tailored to minimize the occurrence of equipment failures well in advance through the systematic scheduling of maintenance activities. These activities are defined through a combination of machine worked hours, historical performance indicators, and the importance of each machine in the production process. By defining these parameters, the maintenance team determines the best times for operating interventions that will not hamper production flow.

The implementation process starts by defining the schedule for maintenance actions such as routine inspections, key parts condition assessments, routine overhauls and even parts substitution. The completion of each maintenance task is recorded in a database that can be monitored in real-time and analysed retroactively. This method enhances the avoidance of unanticipated breakdowns while simultaneously improving the equipment's lifespan, achieving the stability of the production environment and predictability in production outcomes. In addition, Scheduled Maintenance incorporates predictive methods like vibrations, thermal imaging, and oil analysis to identify and flag equipment components experiencing excessive wear proactively or are likely to fail soon so that appropriate preventative measures can be implemented before extensive damages are incurred.

The Planned Maintenance is combined with Production Planning to do maintenance work within scheduled downtimes or during low-production periods. This alignment reduces downtime and improves resource use efficiency since maintenance work is carried out during non-productive hours. The effectiveness of the maintenance plan is evaluated periodically, and steps are taken to resolve any emerging issues or adapt to new changes in production requirements.

The seamless adoption of Planned Maintenance in the framework model optimally enhances the accessibility of the machines by eliminating unanticipated halts and ensuring the machines function under ideal conditions. This method increases trustworthiness and improves costs in the long run while working towards enhancing the SME's plastic equipment manufacturing spend for used equipment.

3.2.3. SMED (Single Minute Exchange of Die)

One of the important components in the model is the Single Minute Exchange of die, which seeks to improve production flexibility while reducing machinery downtime by minimizing set-up and changeover time.

For this SME in plastic manufacturing, the SMED approach is specifically designed to categorize the set-up activities as internal and external procedures. Internal actions are those that the machine must be off to perform, while external actions can be performed when the machine is on.

The first step of the implementation process is agile mapping all the set-up activities to isolate those that can be externalized. This agile mapping includes setting up tools, materials, and documentation needed well before the machine completes its operating cycle. At the same time, adjustments aim to reduce the time spent on internal activities using standing instructions and optimal tooling. Among other things, these adjustments utilize quick-release locks, fixed settings for controllers, and staged supplies.

Improvements in waste elimination and process streamlining are identified when evaluating regular intervals. With both internal and external set-up activities targeted, applying the SMED system eliminates significant time in the changeover process, making the production line more responsive to demand variability. This approach enhances not only the availability of the machine but also fosters other aspects of continuous improvement within the self-contained system of the manufacturing process.

3.2.4. Standardized Work

Standardized Work is the last element of the proposed production model aimed at defining and locking operational tasks to ensure consistency. This systematic approach aims to capture an optimal sequence of activities for each process and reduce variability. Operators execute defined steps alongside descriptive documents that detail the processes, the equipment settings, the materials needed, and the tools needed for the tasks.

Using Standardized Work creates processes that reduce errors and waste by analysing current methods. The Standardized Work model improves process stability and simplification and increases uniformity in task execution. Identifying deviations becomes easier, and training for new operators is streamlined. Continuous Improvement and regular audits are done to meet standards and identify gaps.

Integrated components within a model allow production activities to flow without encountering obstacles. The synergy achieves machine uptime, productivity, and operational stability. The next section of the paper details the interaction of these elements and recognizes the improvements in the SMEs' manufacturing lines.

Unlike existing models implementing Lean Manufacturing or TPM in isolation, this study proposes a fully integrated approach tailored to plastic SMEs' operational and resource limitations. While previous studies (e.g., Mujica-Suarez et al., 2023; Abad-Mendoza et al., 2024) demonstrated partial improvements using SMED or TPM separately, this model combines Standardized Work, Autonomous Maintenance, and Planned Maintenance with a coordinated structure. This holistic integration allows for simultaneous gains in machine availability, change over time, and process consistency—an advancement not addressed by prior fragmented models.

3.3. Model Indicators

To assess the effectiveness of the proposed model, a Small and Medium-sized Enterprise (SME) in the plastic sector was evaluated to measure the availability rate of equipment within the production line using customized measurement criteria explicitly created for this case. The indicators were constructed precisely to allow for performance evaluation so that all factors critical to machine performance would be measured. Such a structured method allowed for further investigation into the important monitoring factors enabling the business to implement effective strategies for improving the operational processes. The thorough evaluation also assisted in identifying bottlenecks and optimising maintenance, thus improving the equipment's operational reliability and efficiency in the production line.

3.3.1. Availability

Availability measures the time equipment is available for production out of the planned operating time. It reflects the machine's reliability and effectiveness in minimizing unplanned downtime, contributing to improved productivity.

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Production Time}}$$

3.3.2. MTBF (Mean Time Between Failures)

MTBF calculates the average time that equipment operates without failure. It represents the reliability of the machinery and helps identify maintenance intervals to optimize performance.

$$\text{MTBF} = \frac{\text{Available Production Time} - \text{Downtime}}{\text{Number of Failures}}$$

3.3.3. MTTR (Mean Time To Repair)

MTTR measures the average time required to repair equipment after a failure. It reflects the efficiency of maintenance processes and supports planning for minimal downtime.

$$\text{MTTR} = \frac{\text{Total Maintenance Time}}{\text{Number of Repairs}}$$

3.3.4. Set-up Time - Machine Start-up

This indicator evaluates the average time required to start machinery before it begins the operation. Reducing set-up time improves production efficiency and reduces idle periods.

$$\text{Set-up Time (Start-up)} = \frac{\text{Sum of Observed Times}}{\text{Number of Observations}}$$

3.3.5. Set-up Time - Mold Change

This metric measures the average time required to complete mold changes in the production process. Efficient Mold changes minimize production delays and enhance operational flexibility.

$$\text{Set-up Time (Mold Change)} = \frac{\text{Sum of Observed Times}}{\text{Number of Observations}}$$

4. Validation

4.1. Validation Scenario

The validation scenario was conducted in a case study corresponding to an SME in the plastics sector located in Lima, Peru. This organization specialized in manufacturing containers and other polypropylene-based products distributed nationwide. The company operated a production line equipped with thermoforming and extrusion machines, whose sustained operation was essential to meet the production volumes demanded by the market. However, one of the main challenges identified in the plant was the low availability of these machines, which significantly affected its operational capacity and, consequently, its competitiveness in the sector. The frequent unplanned stoppages, prolonged set-up, and Mold changeover times generated economic losses due to decreased adequate production levels. This problem highlighted the need to optimize maintenance management and changeover processes in the production lines to increase equipment availability and improve operational efficiency.

4.2. Initial Diagnosis

The case study diagnosis showed a repairable under-machine absence problem in the tray production line, adversely impacting the plant capacity. Furthermore, there is a gap within the industry average compared to the plastics industry, which stands out as having a 90% availability. The studied company's capability stood at 78.6%, reflecting a significant gap. However, this concern was most significantly correlated with high unplanned downtimes, representing

89.27% of the contributing factors to availability loss. Among these, component failure rose to 40.17%, followed by electrical failure-induced shutdowns at 17.85% and insufficient lubrication at 31.25%. In addition, an additional contributing factor related to excessive set-up times was identified at 10.21% of the contribution to the unavailability. This comprises machine standby time at 3.78% and mold exchange at 6.43%. Finally, 0.52% was dominated by a unique selection of unexplained causes. The analyzed state resulted in massive financial repercussions estimated at PEN 5,221,716 of reported losses over the previous year.

4.3. Validation Design

The proposed production management model, which integrates Lean and TPM tools, was validated through a structured pilot process in the case study. This validation lasted four months, encompassing all the proposed methodologies. These included SMED for quick changeovers, Autonomous Maintenance for operator-driven machine care, and Standardized Work to enhance process consistency. The primary objective was to increase machine availability in the production line of the plastic manufacturing SME. A data-driven approach facilitated the assessment of improvements in equipment uptime and process stability, ensuring that the model's application was both impactful and economically feasible for the company.

The proposed model aims to enhance the availability of machines in the production line of a plastic sector SME. It was achieved by incorporating essential elements of Lean Manufacturing and Total Productive Maintenance (TPM), which emphasize optimization on a combination of process streamlining, ergonomics, and macroscopically reducing unplanned downtimes. The implementation was divided into three parts: TPM (Planned Maintenance and Autonomous Maintenance), SMED (Single Minute Exchange of Die), and Standardized Work. Operational and sustained performance improvements drove these interventions. Details of each component are included below.

4.3.1. Implementation of TPM

Total Productive Maintenance (TPM) implementation focused on sustaining equipment functionality and minimizing unexpected production line halts. This approach was organized around two central pillars: Planned Maintenance and Autonomous Maintenance. Both pillars supported maintaining proper productivity in the equipment, thus increasing system uptime and the overall productive lifespan of the equipment.

4.3.2. Planned Maintenance

Planned Maintenance stemmed from a comprehensive series of evaluations and routine modifications. This proactive strategy made it possible to diagnose and fix problems before they developed into major failures, thereby reducing unplanned downtime. During its execution, comprehensive maintenance was performed, including replacing specific components, servicing by lubricating moving parts, and calibrating control systems. Also, intervals of predictive maintenance were established wherein equipment diagnostic techniques such as vibration analysis and thermography were used to identify probable faults in key machinery. These measures provided complete control over the health status of the machines; their functional efficiency improved while their downtimes were reduced. Analysis indicated a 15% reduction in operational downtimes attributed to mechanical failures, which enhanced machine availability from 76.5% to 83.2% by the close of the trial phase. Moreover, introducing a systems-based approach to handle documents improved oversight of all actions taken, enabling better intervention documentation, which enhanced maintenance activity monitoring and analysis of the intervention details, leading to the evaluation of intervention enhancement accuracy.

Figure 2 presents the structured process for Planned Maintenance Implementation, divided into five phases: team formation, initial inspection, standardization, inspection and follow-up, and self-control. It ensures preventive and corrective actions, standardizes maintenance activities and monitors performance indicators for enhanced equipment reliability and operational efficiency.

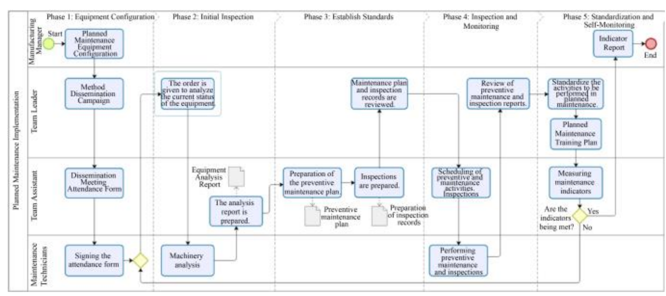

Fig. 2 Phases of Planned Maintenance Implementation

4.3.3. Autonomous Maintenance

The Autonomous Maintenance strategy revolves around equipping operators with the skills needed to attend to basic verification and care activities on the equipment. Operators were trained to perform more active cleaning, inspection, and adjustment processes, which enabled them to refine the detection of anomalies and avert major failures. This approach cut the rate of minor stoppages by 12%, contributing to safer and more orderly operations. Furthermore, the operators' checking of control lists streamlined equipment supervision and management, extending service life and reducing costs associated with corrective maintenance. Also, there was an initiative to make step-by-step operation manuals for all the machines, which would set the minimum standards of inspections and guarantee the detection and acceptance of non-normal performance. Instructors used practical simulations during training to boost responsiveness to minor failures, thus shortening intervention time and fortifying the dominant maintenance culture in the production region.

Area	Machine	Activities	Number of workers	M-H	Frecuency	Maintenance Type	January				February				March				April				May				June				July			
							S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
THERMOFORMING	Thermoforming 03	Cleaning	3	6	M	P		P				P				P				P				P				P				P		
		Lubrication				R																												
	Thermoforming 04	Cleaning	3	6	M	P	P				P				P				P				P				P				P			
		Lubrication				R																												
	Thermoforming 05	Cleaning	3	6	M	P				P				P				P				P				P				P				P
		Lubrication				R																												
	Thermoforming 06	Cleaning	3	6	M	P			P				P				P				P				P				P				P	
		Lubrication				R																												

Fig. 3 Autonomous maintenance plan

Figure 3 illustrates the Autonomous Maintenance Plan, which outlines the scheduled maintenance activities for critical equipment. It includes inspection, cleaning, lubrication, and adjustment tasks performed weekly and monthly. The plan is structured with clear indicators for task frequency, responsible personnel, and evaluation criteria, ensuring effective preventive maintenance and enhanced equipment reliability.

4.3.4. Application of SMED

To streamline set-up and idle times associated with Mold and machine adjustments, the SMED (Single Minute Exchange of Die) system was implemented. This precisely structured technique enabled a 40% reduction in changeover times with SMED's integration; progressive partitioning further decreased the average intervention time from 22 minutes to 13 minutes. This improvement resulted in an 8% increase in the line's production capacity, promoting maximised production cycle efficiency. In addition, standard work procedures were also developed to indicate more redesign possibilities and tools for easier standard adjustments. These improvements enhanced changeover times and responded more readily to market supply and demand slack.

Figure 4 illustrates the start-up process of the thermoforming machine before and after SMED implementation. Each colour represents a different activity, demonstrating significant time reductions and improved process efficiency. The set-up time was reduced from 1.44 to 0.67 hours, optimizing resource utilization and minimizing idle time.

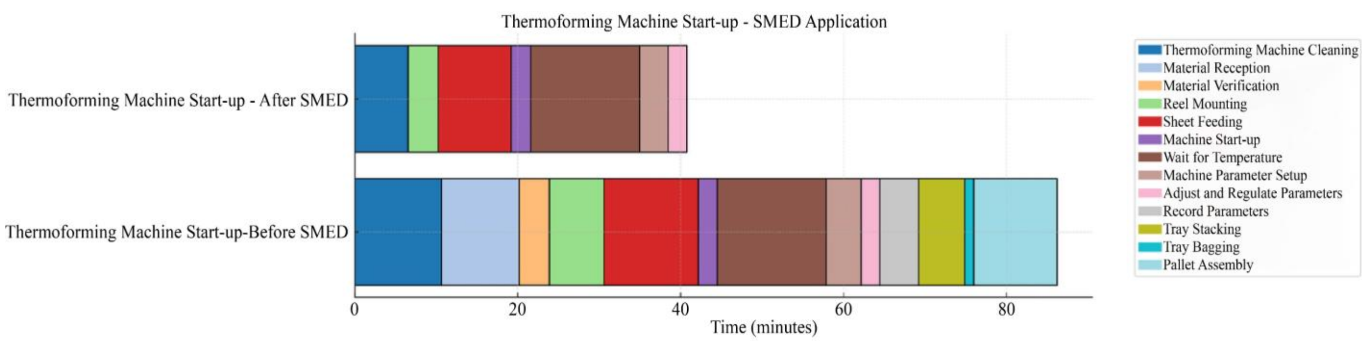

Fig. 4 Thermoforming Machine Start-up - SMED Application

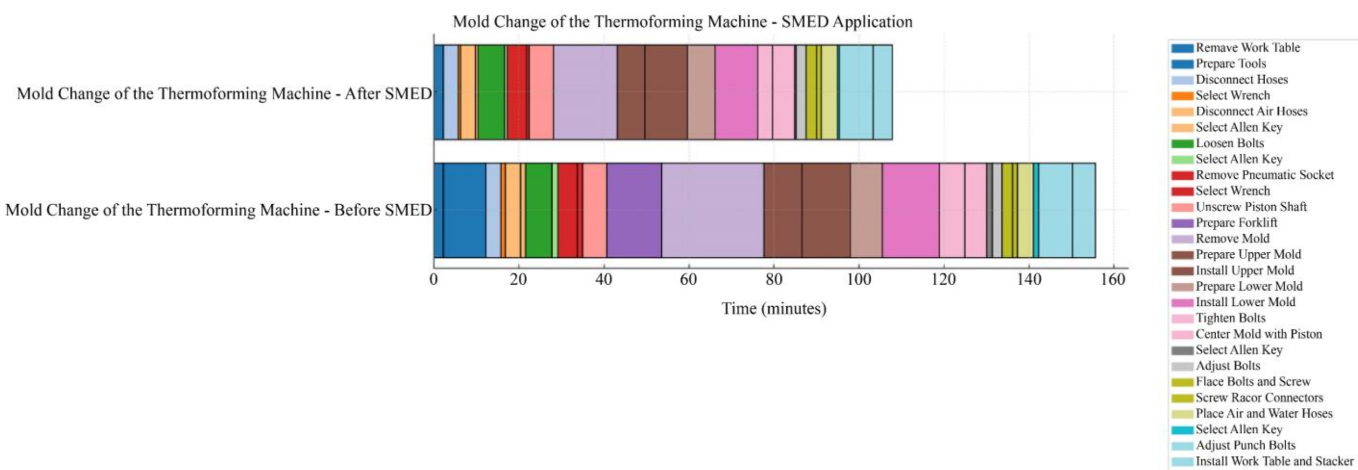

Fig. 5 Mold Change of the Thermoforming Machine - SMED Application

Figure 5 displays the mold change process of the thermoforming machine, comparing the sequence of activities before and after the SMED application. The optimization reduced set-up time from 2.59 to 1.79 hours, streamlining task execution and enhancing production efficiency by minimizing non-productive intervals.

4.3.5. Implementation of Standardized Work

The last step in completing the facelifts on the system was the standardization of operation processes. Creating method and process outlines from each step resulted in optimal machine operations and material handling strategies. This helped reduce variability in operations, ensuring that consistency was achieved in every cycle of production. Furthermore, basic training on the practices led to an operating error reduction of 20% and improved cycle times by 10%. Greater control of the workflow became possible because standardization improved the allocation of resources and resulted in the reduction of material wastage. Uniform practices adopted by the Operators enhanced process and human error predictability.

The use of lean and TPM tools on the production line of the SME in the Plastic sector witnessed enhanced machine availability and optimized operation times. Planned and Autonomous Maintenance integration limited the scope of unplanned downtimes with the help of SMED, while set-up times were drastically improved. Finally, operational consistency related to standardized work decreased error margins, enhancing overall competitiveness and efficiency in the production ecosystem. In parallel, the holistic approach provided scope for the confident identification of improvement gaps, which ensures that the results will be preserved and built upon in the long run.

4.4. Results

Table 1 shows the impact of the proposed production model based on Lean and TPM tools on the leading indicators of the production line. The results demonstrated increased equipment availability, rising from 76.50% to 83.58%, representing an improvement of 9.25%. Similarly, the MTBF (Mean Time Between Failures) increased from 94.08 to 106.25 minutes, reflecting a growth of 12.94%, indicating greater operational stability. On the other hand, the MTTR (Mean Time To Repair) was reduced from 22.13 to 18.55 minutes, showing a decrease of 16.18%, which enhanced the response capacity to failures. Regarding set-up times, machine start-up was reduced by 53.47%, while Mold change was optimized by 30.89%, demonstrating a significant reduction in unproductive times. These results validated the effectiveness of the proposed model in increasing the availability and efficiency of production processes in the plastic manufacturing SME.

Table 1. Results of the pilot

Nº	Indicador	Unit	As-Is	To-Be	Results	Variation (%)
1	Disponibilidad	%	76.50%	90.00%	83.58%	9.25%
2	MTBF (Tiempo Medio Entre Fallos)	Minutes	94.08	103.28	106.25	12.94%
3	MTTR (Tiempo Medio de Reparación)	Minutes	22.13	12.61	18.55	-16.18%
4	Tiempo de Setup - Arranque de Máquina	Hours	1.44	0.36	0.67	-53.47%
5	Tiempo de Setup - Cambio de Molde	Hours	2.59	0.42	1.79	-30.89%

5. Discussion

The findings of this investigation align with the previously documented studies regarding adopting lean manufacturing and TPM in plastic sector SMEs. As Vega-Alvites and Quiroz-Flores noted, using Lean and TPM tools improved the machine availability at an injection moulding plant in Peru, accompanied by a significant decrease in unplanned downtime [3]. In a comparable production setting, Abad-Mendoza et al. confirmed that machine availability underperformed due to Lean and TPM-based maintenance models, showcasing operational inefficiencies and slow breakdown times [12]. Moreover, Mujica-Suarez et al. reported the collective application of SMED and TPM in a plastics company to minimise changeover time, subsequently enhancing productivity [14]. In this investigation, the application of SMED integrated with TPM led to a decrease of 30.89% in mold changeover time. This reduction aligns with the literature, which supports the notion that reducing adjustment times leads to better operational efficiency and availability of plastic SMEs. These findings further the model's reliability, showcasing the ability to improve processes and minimize losses from downtime in analogous manufacturing settings.

5.1. Study Limitations

This study was conducted in a single SME in the plastic sector, selected due to its representativeness in terms of operational challenges common in Peruvian plastics SMEs. While this single-case design allows in-depth analysis and detailed validation, it limits the statistical generalization of results. The absence of a control group was due to operational constraints; however, baseline data were used for comparison to ensure a valid performance assessment. Future research should consider multi-case validation and control groups to enhance causal inference and external validity. Additionally, the short four-month evaluation window constrains the assessment of long-term sustainability. Market demand fluctuations were also not accounted for, which may affect the model's performance under different economic conditions.

5.2. Recommendations for SMEs Based on Results

The research results bring relevant practical insights to help with the operational management of SMEs within the plastic industry. By combining Lean Manufacturing and Total Productive Maintenance (TPM), resource expenditure can be minimized and machine uptime enhanced, thus increasing production capacity while reducing costs associated with unplanned stoppages. Also, greater production agility is within reach with the application of SMED to reduce Mold changeover time, enabling quicker response to demand shifts. These sustained improvements to operational efficiency drive the competitiveness of SMEs in a globalized market where the reduction of downtimes and streamlined processes are vital to maintaining such advantages.

5.3. Future Works

Although this study focuses on the plastic manufacturing sector, the proposed model has the potential to be adapted to other industries characterized by frequent changeovers, machine dependency, and limited maintenance planning, such as food processing, textile production, and small-scale automotive parts manufacturing. Future studies may explore the model's transferability and performance in these sectors to validate its broader industrial applicability. Furthermore, a follow-up assessment is planned six months after implementation to evaluate the persistence of improvements. Monthly tracking of indicators such as machine availability, MTTR, and set-up times, along with periodic audits and operator feedback, will help assess the long-term effectiveness and scalability of the model.

6. Conclusion

The implemented production model with Lean Manufacturing techniques and Total Productive Maintenance (TPM) increased machine utilization and productivity in the evaluated SME of the plastic sector. Also, the application of SMED, Autonomous Maintenance, Planned maintenance, and Standardized Work reduced both changeover and unplanned stoppage time, yielding a 9.25% improvement in machine availability and a 30.89% reduction in mold changeover time. These factors contributed to more stable processes and higher production capacity, demonstrating that the proposed model could effectively strategize and optimize manufacturing processes in plastic SMEs. Moreover, the machine operating efficiency issues linked to breakdowns were systematically reduced through rigorous scheduling of maintenance routines. This improved machine-downtime efficiency, resulting in longer machine life, lower operational interruptions, and increased uptime during production activities. The results underscored the value of integrated approaches that combine Lean and TPM to solve operational problems facing SMEs in more demanding and competitive industrial environments.

The application of Lean and TPM tools in the plastic sector has been extensively covered in the literature, particularly their functional effectiveness in SMEs. The reduction of unplanned downtime and the optimization of changeover processes demonstrate the efficacy of these methodologies. In addition, the study addresses maintenance scheduling concerning process control and standardization, elements that promote sustained operational equilibrium and stability. There is an excellent impetus to an argument directed towards incorporating SME-focused, systemic improvement frameworks in the plastic sector, bolsters agile, competitive capabilities vis-a-vis global market dynamics.

This study offers a unique integrated production model focusing on availability and operational efficiency metrics for plastic industry SMEs. Previously studied lean or TPM stand-alone implementations have not proven to be successful. This work exemplifies the need to consider holistic systems for SMEs to make meaningful and operationally focused advancements. Not only does this model eradicate the self-imposed and prevalent productivity barriers, but it creates a structure for ascending towards sustained self-improvement through active maintenance and standardization frameworks.

Further studies may focus on applying the suggested model in various industrial settings to evaluate its flexibility and scalability across different manufacturing environments. The model could be further improved by integrating some Industry 4.0 technologies, such as predictive maintenance and real-time monitoring, to increase machine reliability and streamline processes. Further, longitudinal studies are necessary to confirm the sustained improvements over time and to study the effects of changing market conditions and production volumes on the model.

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