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Original Article

Addressing Operational Challenges in Plastic Manufacturing SMEs: A Lean-TPM Model for Improved Efficiency and Quality

Angela Johana Callan-Villanueva[1], Sebastián Alejandro Núñez-Gonzales[1], Wilson David Calderón-Gonzales[1,*]

[1]*Faculty of Engineering, Industrial Engineering Career, Universidad de Lima, Perú.*

[*]*Corresponding Author : wdcalder@ulima.edu.pe*

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Abstract - *The research investigated the challenges faced by SMEs in the plastic product sector, particularly regarding inefficiencies in machine availability, prolonged setup times, and high defect rates. Previous studies highlighted the potential of Lean Manufacturing and Total Productive Maintenance (TPM) to optimize operations, but limited research focused on their integration in this sector. The research tackled these problems by implementing a Lean-TPM production model that integrates SMED and Poka Yoke with maintenance approaches. Important findings were the average 35.99% reduction in setup times, a 32.66% increase in MTBF, a 39.71% reduction in MTTR, and a 23.19% decrease in defective products. These results prove the effectiveness of the model in enhancing productivity and the quality of products to other SMEs. These results are of great importance in productivity and quality of products for other SMEs, thus contributing greatly to Small Engineering Enterprises. This study significantly contributes to industrial engineering by bridging the theory and practice gaps. Further studies should investigate model adaptability, the integration of technologies of Industry 4.0, and the evaluation of the changes in organizational culture toward competitiveness over time.*

Keywords - *Lean Manufacturing, Total Production Maintenance, Plastic Manufacturing SMEs, Operational Efficiency, Quality Improvement.*

1. Introduction

Small and Medium-sized Enterprises (SMEs) dealing with plastic products have both economic and strategic significance in parts of the world, such as Latin America and Peru. It is important to note that this industry is a major source of employment and fosters sustainable economic growth. A study by the Lima Chamber of Commerce shows that SMEs account for around 99% of formal businesses in Peru and provide 75% of employment in the country alone [1]. The worldwide plastic market has grown steadily due to demand for diverse uses ranging from packaging materials to industrial parts [2]. The plastics industry in Latin America has also grown despite facing stiff challenges from international competition and the need to implement cleaner and more efficient technologies [3]. It is apparent that SMEs in this region undertake a large share of innovative economic activity; thus, their role in the region's economic development is of great significance. Nevertheless, SMEs in the manufacturing plastic sector experience production challenges that limit their competitiveness and sustainability. One of the primary issues is the lack of tools due to equipment failure due to machine upkeep, poor setup processes, and mistakes in calibration and parts handling [4]. Maintenance failures generate long downtimes, negatively affecting production capability and product quality [5]. Also, setup processes are essential for operational efficiency, tend to be long and complex, and consume time, which is otherwise useful [6]. All these contribute to a loss in productivity and increased operating expenses, which can be very harmful for SMEs working with low-profit margins [7].

Overcoming these issues is important to increase the competitiveness of SMEs in the plastics industry. The use of methodologies like Lean Manufacturing and Total Productive Maintenance (TPM) provides efficient ways of optimizing production processes and waste reduction [8]. Lean Manufacturing aims to eliminate waste and endeavours for constant improvement, resulting in efficiency improvement and reduced costs [9]. At the same time, TPM concentrates on preventive maintenance and employee participation in caring for machines, which increases machine availability and reliability [10]. These approaches are capable of solving urgent problems and creating an SMEs-friendly environment that becomes self-sustaining based on continuous improvement. Although there is increased adoption of Lean

Manufacturing and TPM, this gap in the literature still needs to be covered.

Although numerous investigations focus on the adoption of these tools in large organizations, scant work has been done on their use within small and medium enterprises (SMEs) in the plastic industry [11]. This study seeks to accomplish this objective by designing a production model that combines tools of Lean Manufacturing, like SMED and Poka Yoke, with TPM elements of autonomous and planned maintenance [12]. This model is meant to enhance operational effectiveness and, at the same time, offer a means for SMEs to utilize these practices for their benefit. Its focus on SME-specific characteristics is what makes the model novel, and therefore, it is more sustainable and competitive in the plastics sector [13].

This dissertation differs from the others because it emphasizes the interface between Lean Manufacturing and TPM in the context of plastic sector SMEs, which has not been well covered in previous studies [14]. This research benefits the academic literature and presents a powerful tool for SMEs by providing a comprehensive approach to adopting these methodologies and enhancing performance and sustainability in a highly competitive environment [15].

2. Literature Review

The literature review concerning the application of continuous improvement methodologies in manufacturing plastic products by small and medium-sized enterprises (SMEs) is crucial in determining how these techniques can add value to their production processes. This analysis concentrates on five methodologies: Lean Manufacturing, SMED, Poka Yoke, Autonomous Maintenance, and Planned Maintenance. Each sub-section is based on current studies which emphasize the applicability and importance of these methods in the case of SMEs.

2.1. Lean Manufacturing in Plastic Product SMEs

The Lean Manufacturing model is adopted in many sectors, including among plastic product industry SMEs. It is known that this model seeks to reduce waste while promoting improvement, which increases productivity and competitiveness. Studies show that applying Lean practices greatly enhances productivity while lowering operating expenses [16]. Furthermore, some SMEs in the food industry, parallel to plastic products SMEs, have reported increased profits and customer satisfaction after adopting the Lean practices [17].

Despite these benefits, adopting Lean is not easy. SMEs face significant barriers like reluctance to adopt change and lack of adequate training, which leads to ineffective adoption [18]. Process innovation and effective management are key to leveraging Lean practices in SMEs [19]. Thus, plastic product SMEs are required to implement Lean but, at the same time, shift their focus to removing barriers during adoption.

2.2. Application of the SMED Methodology

The SMED (Single-Minute Exchange of Die) is equally relevant for SMEs in the plastic products sector because time savings associated with reducing tool changeover times can be very beneficial. Applying SMED reduces downtime much more, which enables SMEs to respond to market needs more efficiently [20]. It also assists in the optimization of production processes, enabling firms to remain competitive in an aggressive market.

Adopting SMED enables SMEs to lower changeover times and enhance the quality of the end products, which is very important in the plastic industry [21]. Nevertheless, strong commitment from management and employee training is needed for effective SMED implementation [22]. In order to effectively benefit from SMED, these SMEs must invest heavily in training and development.

2.3. Poka-Yoke Methodology

The Poka-Yoke methodology is focused on avoiding mistakes during production processes and is useful for SMEs in the plastic goods industry, where product quality is critical. Research shows that Poka-Yoke significantly reduces defects and enhances product quality in SMEs [23]. This strategy helps businesses prevent mistakes from becoming complicated issues, thus decreasing costs from rework and scrap.

Implementing Poka-Yoke methods improves the product and enhances customer satisfaction, which is very important in most markets [24]. On the contrary, employee reluctance to change the processes may slow the implementation program. The involvement of employees in the process and sufficient training are key for a successful shift to strong quality systems.

2.4. Autonomous Maintenance

Autonomous Maintenance assigns basic maintenance responsibilities to the machine operators, which nurtures a sense of ownership and responsibility among workers. Research indicates this approach enhances equipment availability and lowers maintenance expenses in small and medium businesses [25]. It enables companies to detect possible issues in advance, thus averting expensive breakdowns.

Engaging workers in maintenance tasks promotes continuous improvement and enhances motivation and job satisfaction [26]. On the other hand, the effectiveness of Autonomous Maintenance in SMEs depends on the degree of employee training and the organizational culture of continual improvement that the company embraces. This guarantees the efficiency of the methodology alongside the company’s operational sustainability in the long run.

2.5. Planned Maintenance

With Planned Maintenance, SMEs can allocate maintenance periods in advance to reduce disruptions attributable to unplanned machine downtimes. Planned maintenance improves efficiency and significantly lowers costs in an organization's operations and decision-making processes [27]. This strategy helps firms resolve issues before they disturb the production workflow, critical in the plastic products sector, where downtimes can result in considerable losses.

Planned Maintenance implies better operational efficiency and a longer useful life of a given asset, which is critical to an SME with low-profit margins [28]. For this approach to work effectively, a certain level of commitment from management and some form of investment into maintenance management systems is necessary. Maintenance management software should be considered by SMEs in order to enable better planning and tracking of maintenance tasks.

Lean Manufacturing, SMED, Poka-Yoke, Autonomous Maintenance, and Planned Maintenance are some approaches that can enhance the competitiveness of plastic products SMEs. The more critical issue is removing the barriers to implementation and ensuring a clear commitment toward staff training and development. These SMEs navigate the challenges that continuously seem to be there in a changing market environment and should harness these operational approaches for enhanced efficiency and greater sustainable outcomes.

3. Contribution

3.1. Proposed Model

A model of production that takes into account Lean Manufacturing principles and Total Productive Maintenance (TPM) components is illustrated in Figure 1. It is oriented towards improving operational processes by integrating efficiency, availability, and quality strategies in production activities. The model was devised into three key phases, each designed to deal with a specific aspect of industrial performance. The first phase was time optimization, in which tools like SMED were used to reduce setup times and eliminate waste to streamline processes without compromising operating standards. In the second phase, attention was turned to ensuring availability through autonomous and planned maintenance per the principles of TPM, which aimed to keep operational and system interruptions to a minimum and continuity to a maximum. Lastly, the third phase ensured quality by using Poka Yoke, stressing controlled standard work methods to minimize drastic errors within critical stages of production. As shown in the figure, this set of activities demonstrates how the various phases interact towards achieving a strong and flexible production system capable of continuous operational efficiency improvement and reducing losses in the industrial ecosystem.

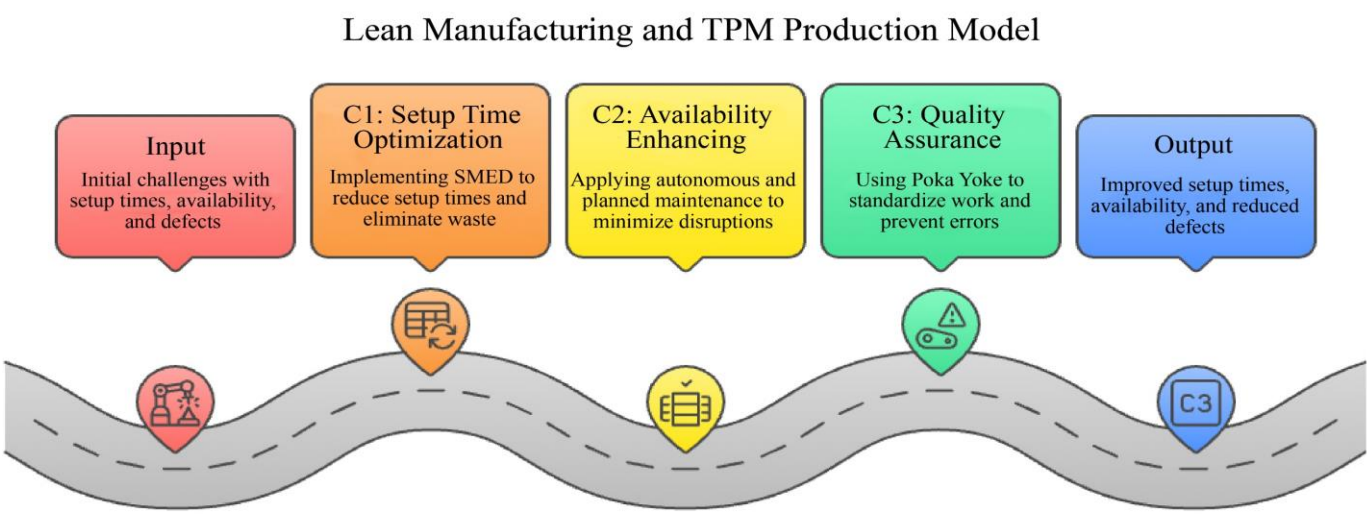

Fig. 1 Proposed model

3.2. Model Components

The model proposed in this paper, illustrated in Figure 1, is designed as a holistic solution to improve efficiency in an industrial setting through the application of Lean Manufacturing in conjunction with Total Productive Maintenance (TPM). This model was created to address some of the most important gaps in production activities, including time allocation, equipment availability, and service quality. By integrating SMED, TPM, and Poka Yoke into a system's cyclic process, the model sets out to achieve continuous improvement along with sustainable increases in productivity. The model design identifies a gap that focuses on the current predisposition for flexible and elastic approaches to meeting operational requirements while optimizing resource utilization. Each component is critical to creating an ecosystem that minimizes waste, reduces downtimes, and erases defects, thus improving overall industrial performance. The next sections describe the particular steps of the model, clarifying goals, methods, and results for every single step.

3.2.1. Component 1: Time Optimization through SMED Implementation

The first stage of the model focused on lowering setup times and smoothing processes with the application of the Single Minute Exchange of Dies (SMED) technique. This step was essential in mitigating time-related inefficiencies prevalent within production systems. This process started with examining setup activities in a single internal and external stage. Internal activities that needed the machine to stop working were scrutinized to the point where these processes could be inverted. External activities were improved through the application of standardization and simplification processes.

Moreover, the focus was on removing non-value-adding processes, which consisted of turning manual, repetitive activities into automated or semi-automated ones. Tools and fixtures were arranged to facilitate their use, and operators were offered training to enable them to execute fast and efficient setups. The addition of flexibility allowed the production system to adjust to changes in demand and product configurations more easily, a fundamental tenet of Lean Manufacturing. This phase of the work sets the stage for operational adaptability and responsiveness to changes while also reducing setup time.

3.2.2. Component 2: Ensuring Equipment Availability through TPM

In the second step, the model highlighted equipment accessibility as a prerequisite for continuous production. In the Total Productive Maintenance (TPM) paradigm, autonomous and planned maintenance was incorporated to extend machinery life and ensure operational reliability. Autonomous maintenance aims to assign operators to inspect their machines through basic cleaning, lubrication, and adjustment tasks. This approach increased operator participation and permitted early identification of emerging problems before they became catastrophic failures.

On the contrary, planned maintenance was executed through predictive and preventive means. Within predictive maintenance, data analysis techniques such as vibration analysis and thermal imaging were employed to manage wear-and-tear damage proactively. Preventive maintenance tasks were timed with equipment usage and specified by manufacturers to maximize reliability and minimize the chances of unexpected outages. Combining these strategies enhanced the operator's and maintenance staff's motivation to attend to the equipment care and use, minimising equipment downtime and increasing productivity.

3.2.3. Component 3: Quality Assurance through Poka Yoke

In the third phase, quality assurance was further improved through the implementation of Poka Yoke, which aims to eliminate errors by fixing them at the source. This phase required a careful analysis of significant production steps to determine where shortcomings occurred and how to develop mechanisms that would render these shortcomings impossible. Standardized work procedures were designed to minimise human error to guarantee the same outcome in every production cycle. Sensors and alarms as error-proofing devices were added to the production line so that appropriate measures could be instantly executed.

Moreover, the scope of standardization was also extended to the design of workstations and tools to achieve an optimal ergonomic setup that minimizes fatigue for the operator. Various inspections of working products were performed at different points of the process so that any faults could be fixed immediately. The Poka Yoke system, by its nature, not only helped improve product quality but also assisted in reducing waste and rework, thus improving operational efficiency as a whole.

3.2.4. The Cyclical Nature of the Model: Continuous Improvement

A key characteristic of the proposed model is its cyclic structure. This feature highlights the iterative stages of the improvement processes. The phases of time optimization, equipment availability, and quality assurance illustrated in Figure 1 are sequential and interdependent. This design aims to ensure that every cycle of the system is accompanied by learning that adjusts to the next cycle, thereby creating a system responsive to the operational context.

For example, SMED-driven reductions in setup costs directly lead to enhanced equipment availability because machines are not idle for as long. Likewise, enhanced equipment reliability through TPM enables proper quality outputs and reduces the FOR work, resulting in time savings that can be used for further time optimization. Such dependence illustrates the model's holistic nature, where the enhancement of any single element positively impacts the entire production system.

3.2.5. A Framework for Sustainable Industrial Excellence

This model improves the Lean Manufacturing and TPM systems by addressing the complexities in today's production systems. The model improves efficiency and fosters a culture of continuous improvement by focusing on time, equipment, and quality. Its applicability in different industrial contexts makes it relevant for professionals and researchers. With its adaption, companies can create a flexible production system that can sustain productivity improvement, minimize operational waste, and strengthen the resilience needed to respond to market dynamics.

3.3. Model Indicators

The Lean-TPM production model tailored for plastic manufacturing SMEs was evaluated using specialized metrics designed for this specific purpose.

Such metrics were developed for analyzing case study performance, providing a solid foundation for analyzing critical components of the production process in an SME context.

The systematic approach provided a complete assessment of key performance indicators. This comprehensive analysis helped effectively control and enhance the processes in the SME.

3.3.1. Setup Time

Setup time captures the time taken to read either equipment or processes ahead of production. It indicates how effective an organization is in solving delays in movement during operational cycles. Improving flexibility in production depends largely on how much setup time is reduced.

$$\text{Setup Time} = \frac{TSET_i - TSEF_f}{TSET_i}$$

3.3.2. MTBF (Mean Time Between Failures)

MTBF measures the average time an organization operates machinery between failures, offering a perspective on reliability. A greater MTBF value correlates with better performance and fewer interruptions.

$$\text{MTBF} = \frac{\text{Operating Time}}{\text{Number of Failures}}$$

3.3.3. MTTR (Mean Time to Repair)

MTTR measures the meantime taken to repair a machine after it breaks down. Maximum efficiency in maintenance activities and faster comeback from loss of productive time are reflected by lower MTTR values.

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

3.3.4. Machine Availability Rate

This metric gauges the proportion of time machinery works compared to the available time. It reveals the extent of usage of the equipment during production activities.

$$\text{Availability Rate} = \left(\frac{\text{Available Time}}{\text{Production Time}}\right) \times 100$$

3.3.5. Defective Products Rate

The defective products rate quantifies the percentage of faulty items relative to the total output. It is a critical indicator of process quality and consistency.

$$\text{Defective Products Rate} = \left(\frac{\text{Number of Defective Products}}{\text{Number of Injected Products}}\right) \times 100$$

4. Validation

4.1. Validation Scenario

The validation scenario was conducted in a case study involving a company based in Lima, Peru, specializing in manufacturing plastic products through injection molding. The company prioritized adherence to the highest standards in occupational safety, health, and environmental regulations, considering its personnel its most valuable asset. It focuses on delivering high-quality products at competitive prices and ensuring timely delivery to fulfil customer projects while contributing to the community and surrounding environment. Significant technological resources were dedicated to maintaining the quality and durability of its plastic product components and formulas. The company’s production lines served diverse sectors, including construction, home goods, pharmaceuticals, agroindustry, and toys. Among these, construction (29.72%), home goods (28.81%), and pharmaceuticals (19.81%) represented the highest production volumes, reflecting its strategic focus on high-demand markets while also customizing production to meet specific requirements from corporate clients.

4.2. Initial Diagnosis

The diagnosis conducted in the case study identified low machine availability due to unscheduled downtimes, reaching a level of 66%, which created a gap of 5.5% compared to the sector average of 71.5%. This issue caused a significant economic impact, representing a 13% reduction in total revenues, equivalent to 197,088 PEN. Among the most critical factors, 32% of the causes were attributed to the lack of maintenance of hydraulic and mechanical components, with inadequate cleaning of planetary gears (12%) and incorrect oil levels in hydraulic presses (11%) being key contributors. Additionally, deficiencies in preparation for part changes accounted for 29%, with delays in changing hydromechanical guide bars (11%) and overtime in assembling cooling systems (10%) standing out as major issues. Errors in handling calibrations and parts contributed 19%, with significant factors including delays in spindle assembly (8%) and misalignment of movable plates (6%). Finally, 20% of the remaining causes were categorized as other diverse factors, highlighting the complexity and breadth of the identified problem.

4.3. Validation Design

The pilot validation method was employed to validate the proposed production model, incorporating the Lean and TPM tools. The case study employed this method for four months, encompassing all the suggested techniques. These consist of planned maintenance, stand-alone maintenance, Poka Yoke, and the SMED instrument. The following is a comprehensive description of each of these instruments.

The solution was implemented in the case study through an integrative design incorporating the SMED, TPM, and Poka Yoke methods. This strategy sought to fix the low machine availability due to unplanned downtimes, enhance production activities, and minimize costs. Throughout the case study, the emphasis during the design and development stages was on achieving exactness, flexibility, and perpetual change.

4.3.1. Conceptual Model Design

The model was built based on a comprehensive literature review from 2019 to 2023, which included lean manufacturing tools. The designed model combined the three methods, SMED, TPM, and Poka Yoke, into a step-by-step implementation process. This provided an orderly and methodical approach, starting with an organization-wide training and sensitization campaign. This phase was very important in guaranteeing that all staff members were oriented and possessed the correct information and skills to play a meaningful role.

4.3.2. C1: Implementation of SMED

The first phase emphasized the Single-Minute Exchange of Die (SMED) process. This is concerned with examining the setup activities internal and external to the operation to optimize procedures and minimize changeover durations. These processes involve the following activities: Activities Included: Initial Time Measurements: Set-up events were timed for several machine operations within a work centre to establish baseline data. This involved capturing outstanding and in-progress times for each setup step and calculating inefficiencies afterwards. Tasks performed in the setup process were divided into external and internal activities. Internal activities while the machines were operational were set to the lowest possible value, while external activities done while the machines were working were set to the highest possible value.

Conversion of Internal to External Activities: A significant effort was made to convert as many internal activities as possible into external ones. For instance, preparatory tasks such as tool gathering and cleaning were reorganized to occur prior to machine downtime.

Monitoring and Continuous Evaluation: Regular assessments were conducted to ensure sustained improvements. This included periodic recalibration of processes based on real-time data.

As a result of this phase, setup times were reduced by an average of 36.33%. Specific examples include:

Guide Bar Changes: Time reduced from 48 minutes to 30 minutes and 20 seconds, a 37% improvement.

Cooling System Assembly: Reduced from 3 hours and 41 minutes to 2 hours and 18 minutes, achieving a 38% reduction.

Spindle Mounting: Time decreased from 3 hours and 30 minutes to 2 hours and 18 minutes, representing a 34% improvement.

All these changes improved the availability of the machines, which enhanced the productivity and efficiency of operations.

In Table 1, the results of the time reductions for SMED's set-up activities are given for three chosen activities. For changing hydromechanical guide bars, the setup time improved from 48 minutes to 30 minutes and 20 seconds, which is a 37% improvement. The times for the assembly of the cooling system was reduced from 3 hours and 41 minutes to 2 hours and 18 minutes, which is a 38% reduction; the spindle mounting time was reduced from 3 hours and 30 minutes to 2 hours and 18 minutes, which means a 34% improvement. The mean improvement in overall activities was calculated as 36.33%, which shows how effective the SMED tool is.

Table 1. Setup Time Reduction Achieved with SMED Implementation

Setup activity	Machine	Setup time Before	Setup time After	%
Change of hydromechanical guide bars	VML-63PVC	0:48:00	0:30:20	-37%
Cooling system assembly	VMAX-90	3:41:58	2:18:33	-38%
Spindle mounting	VMHSJP-100/45B	3:30:04	2:18:25	-34%
Average estimated improvement applying the SMED tool				**-36.33%**

4.3.3. C2: Total Productive Maintenance (TPM)

The second step centred on the execution of TPM, particularly focusing on autonomous and scheduled maintenance activities. This step was split into four mini-steps:

Preparation

Gap audits were performed on the current maintenance exercises to define shortfalls. Each machine was assigned a tailored maintenance plan that was based on the machine's performance history.

Induction

Training was held to introduce staff to basic autonomous maintenance activities. Operators were taught how to conduct simple periodic inspections, lubrication, and basic servicing to instil a sense of responsibility.

Execution

Maintenance work was carried out in a phased manner to achieve a smooth production flow. Daily checks for autonomous maintenance were basic, while planned maintenance actions dealt with more sophisticated problems.

Evaluation

The extent of the effectiveness of TPM was evaluated using MTBF and MTTR. In this case, the results were remarkable:

MTBF went up from 26.85 hours to 35.62 hours, an increase of 32.66 per cent.

MTTR, from 15.11 hours to 9.11 hours, was a reduction of 39.7%.

The results confirmed that TPM successfully improves machine reliability and minimises downtime. The systematic procedure guaranteed control of how maintenance activities were carried out and improved over time. Figure 2 depicts the verification of the autonomous maintenance pillar in the TPM framework through its impact on the MTBF indicator. It analyzes the MTBF figures pre-and post-implementation of the autonomous maintenance pillar. The red indicates the initial MTBF value of 26.85 hours, representing a low machine operation time value without failures. After the implementation of the TPM strategy, the MTBF value increased to 35.62 hours, as indicated by the green colour. This value is higher by 32.66 per cent compared to the previous one. The increased operational time between failures made possible by autonomous maintenance demonstrates its tremendous impact on machine reliability and production efficiency in the case study.

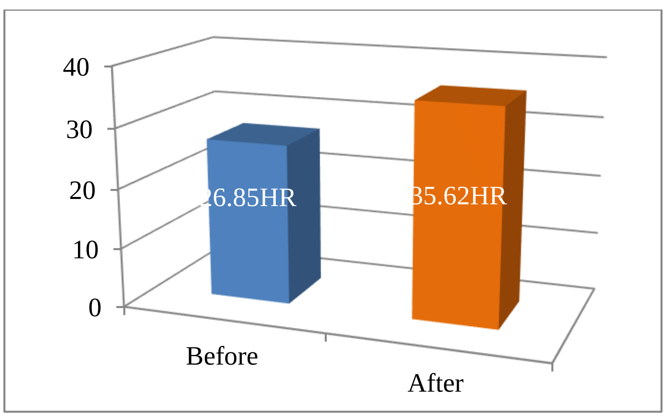

Fig. 2 Improvement in MTBF After Autonomous Maintenance Implementation

Screenshot 3 shows the validation of TT maintenance within the TPM approach, especially on the Mean Time to Repair (MTTR) indicator. The comparison of MTTR before and after performing planned maintenance is presented. The red colour portrays the longer cycle of MTTR, which was 15.11 hours. Once the TPM approach was implemented, the MTTR decreased to 9.11 hours, which is depicted in green, indicating a 39.7% improvement. The green highlighted MTTR shows fewer hours of repair time, which is what the TPM approach aimed to achieve. This case study shows the benefits of this particular approach to maintenance.

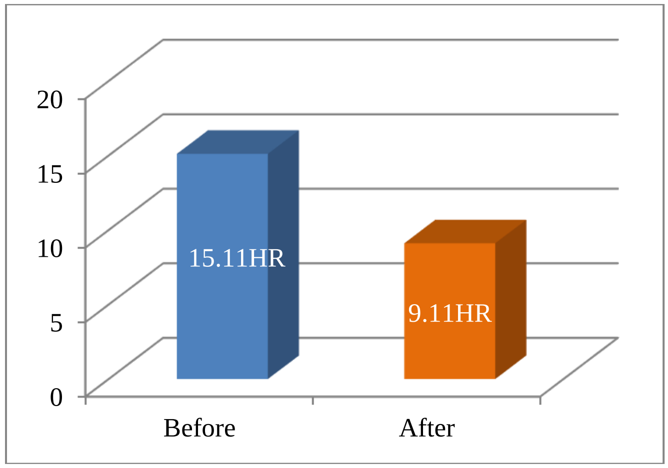

Fig. 3 Reduction in MTTR After Planned Maintenance Implementation

4.3.4. C3: Poka Yoke for Error Prevention

The implementation of Poka Yoke in this phase focused on reducing operational misunderstandings. It was based on both error detection and prevention mechanisms. This phase included the following activities:

Locate Deficiency Possessing Access Zones: Significant gaps in the production steps known to result in errors were located. For example, the gaps within the calibration of sensors and the manual assembly operations were pointed out as key error sources.

Use of Discrepancy Signalling Devices: Signs and alarms were installed for real-time abnormality detection. These devices involved visual, acoustic, and vibratory-based detectors tailored for particular machine needs.

Operator Signal Training: The operators were taught basic signal reception and reaction skill sets. This training lesson was based on a preventative approach before things go wrong.

Evaluation and Optimization: The effectiveness of the changes was evaluated by Poka Yoke measures of post-production defect rates and cycle times. The yield results were astonishing:

Defects on products were reduced by 23 per cent.

The average cycle time was reduced by 16 per cent, which increased production efficiency.

This case study justified a large reduction in operational variance, and an infusion of Poka Yoke reduced inconsistencies in product quality.

Integrated Model Benefits

The combination of SMED, TPM, and Poka Yoke provided a synergistic effect that magnified the effect of each methodology. Not only did the model aim to solve short-term operational problems, but it also set up a structure for long-lasting improvement. Some of the primary benefits were:

“With Better Availability of Equipment: An increase of 22% from 66% to 88% was recorded.”

S/71,994.24 is saved yearly as downtime and efficiency losses are minimized.

“Better Operational Indices: The growth of MTBF, reduction of MTTR, and defects together resulted in an increase in OEE and equipment productivity.”

4.4. Results

Table 2 records the results of the pilot application of the Lean-TPM production system in an SME that manufactures plastic products. The results of these indicators before the model’s application were considerably low. Setup time was diminished by 35.99%, while operational reliability improved as the Mean Time Between Failures (MTBF) increased by 32.66%.

Maintenance efficiency was improved as the Mean Time To Repair (MTTR) lowered by 39.71%. Moreover, an increase of 33.33% in the availability rate of a machine was noticed, along with a reduction of 23.19% in the rate of defective products, presenting the enhancement of processes and quality efficiency.

Table 2. Results of the pilot

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Setup Time	**hrs**	2:40:01	1:25:00	1:42:26	-35.99%
MTBF (Mean Time Between Failures)	**hrs**	26.85	40:10	35.62	32.66%
MTTR (Mean Time to Repair)	**hrs**	15.11	8:10	9.11	-39.71%
Machine Availability Rate	**%**	66%	90%	88%	33.33%
Defective Products Rate	**%**	4.96%	3%%	3.81%	-23.19%

5. Discussion

The data from this study parallels closely with existing literature, especially regarding enhancing operational efficiency through the amalgamation of Lean Manufacturing and TPM.

For example, the improvements in setup times through SMED, achieving an average of 36.33% improvement, agree with the empirical results of Yadav et al. [20]. These authors claimed that SMEs that adopted this methodology reported significant productivity improvements. In the same way, Hu et al. [25] noted the importance of autonomous maintenance for equipment availability, which is supported by the large increase in MTBF (32.66%) and the reduction of MTTR (39.71%).

Furthermore, the 23% reduction in defective products supports the work done by Psomas et al. [23], who argued that Poka Yoke, an error-proofing device, improved product quality. The attention given to this study on the plastic products industry addresses peculiar issues like variation in product demand and high-quality standards, unlike the general focus of several authors such as Seneviratne et al. [24] and Abdallah et al. [19]. These research findings offer a specific sector perspective that adds practical value to the existing literature and knowledge base.

5.1. Study Limitations

This study has a primary shortcoming in that it relies on a single case study, which may not be applicable across different industries or regions. While the four-month pilot implementation period is sufficient for initial validation, it does not allow evaluation of long-term impacts like sustained increases in engagement or decreases in defects over time. Furthermore, self-reported performance data for some metrics can introduce biases that affect the results. The study also makes an incorrect assumption that every employee follows the set methodologies, which does not consider the differences in effectiveness across teams.

5.2. Recommendations for SMEs Based on Results

The outcome of this study contains critical practical relevance for Small and Medium Enterprises operating in the plastic products industry. The implementation of the suggested Lean-TPM production model within SMEs has the potential to eliminate significant deficiencies, which would improve productivity, lower costs, and enhance the quality of products. Adopting SMED, along with autonomous maintenance and Poka Yoke, improves SMEs' reliability and competitiveness in fast-changing business environments. The lower defect rates and cycle times also support the shift towards more sustainable manufacturing, which increases the importance of the model in modern industrial contexts.

5.3. Future Works

Further examination is required into the practicality of implementing the model across various SMEs from different industrial sectors. Extending the scope of the research would enable assessment of the sustainability of the gains achieved, alongside measurement of other organizational changes over time, like changes in organizational culture or ongoing employee participation. Moreover, the model's efficiency may be improved by applying sophisticated data analysis and tools of Industry 4, such as algorithms for predictive maintenance and monitoring of processes in real-time. Lean-TPM adoption in economically limited SMEs needs further exploration concerning its value versus costs to inform better management's attempts to employ such approaches.

6. Conclusion

This research confirms that the application of the Lean-TPM model results in significant operational efficiency improvement among SMEs from the plastic products industry. Important findings include the 35.99% reduction in setup times, the 32.66% increase in mean time between failures, and the 39.71% decrease in the mean time to repair. These figures show the effectiveness of SMED, autonomous maintenance, and Poka Yoke integration. Furthermore, the machine availability rate increased by 33.33%, and the rate of defective products declined by 23.19%. These results indicate the model's ability to mitigate inefficiencies, augment equipment reliability, and enhance product quality within an unmet implementation period.

This research underscores the importance of specialized operational models in resolving specific problems confronted by SMEs within the plastic industry. The study highlights the power of Lean and TPM methodologies in promoting competitive and sustainable practices by emphasising waste reduction, time optimisation, and error prevention. The significance of improving operational efficiency in these firms is extremely high, given the industry's contribution to economic growth. This study fills a significant gap in the literature by offering a practical approach to the implementation of these methodologies in small-sized enterprises.

This research enhances the body of knowledge within industrial engineering by providing a model that can easily be adapted to the context of SMEs. Additionally, this research presents practical views towards combining Lean Manufacturing and TPM tools and makes it possible for integration on smaller businesses with lesser resources, not just on larger enterprises. Besides, this explains how specific approaches to change can significantly impact operational measures. The results are important to the academic and professional audience and are focused on process improvement, operational efficiency, and excellence.

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