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Implementing Lean and TPM for Machine Availability Enhancement: A Case Study in the Peruvian Food Processing Industry

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Abstract

The food manufacturing industry, especially small and medium-sized enterprises (SMEs), faces critical challenges related to operational inefficiencies and machine availability. Previous research has highlighted the need for Lean Manufacturing tools like 5S, SMED, and Total Productive Maintenance (TPM) to address these issues. This study aimed to improve equipment availability and reduce downtimes in a food processing SME in Peru, focusing on optimizing production through these methodologies. The proposed solution involved the application of Lean tools to restructure workplace organization, streamline machine setup times, and implement autonomous maintenance practices. Key findings demonstrated a significant improvement, with equipment availability increasing from 77.01% to 82%, and a reduction in setup times by 30.81%. The study's contribution is both academic and practical, providing a replicable model for similar SMEs in the food industry. Future research should explore further adaptations of Lean-TPM frameworks to enhance sustainability and long-term operational performance across various sectors.

Keywords
Lean Manufacturing, Total Productive Maintenance, Machine Availability, SMED, Food processing SMEs.

1. Introduction
The importance of the small and medium-sized enterprises (SMEs) in the food manufacturing sector is undeniable, both globally and in specific contexts such as Latin America and Peru. This sector not only represents a crucial source of employment, but it is also essential for food security and economic development. According to the Food and Agriculture Organization of the United Nations (FAO), SMEs in the food industry are responsible for a significant portion of global food production, contributing to the diversity and sustainability of food systems (Batista et al., 2021). In Latin America, SMEs represent approximately 99% of all businesses, and their role is even more prominent in the food sector, where it is estimated that they generate more than 50% of jobs (Beske et al., 2014). In Peru, SMEs are

vital to the economy, accounting for 95% of businesses and generating around 80% of jobs in the private sector (Restrepo et al., 2022). This context highlights the need to strengthen the competitiveness and efficiency of these companies to ensure their sustainability and growth in an increasingly globalized market.

However, food manufacturing SMEs face numerous production problems that limit their ability to operate efficiently. One of the most critical challenges is the low availability of machines in the production process, which results in unproductive times and operational failures. These interruptions may be caused by machine stoppages due to technical failures, as well as long downtimes related to machine setups and the lack of order and cleanliness in workstations (Singh et al., 2018). Research indicates that up to 68% of manufacturing plants do not implement methodologies such as 5S, which could help mitigate these issues (Bayo-Moriones et al., 2010). Additionally, inadequate training for operators can lead to errors that exacerbate the situation, resulting in a cycle of inefficiency that affects not only production but also the quality of the final product (Singh & Ahuja, 2015). The implementation of Total Productive Maintenance (TPM) practices and Lean methodologies, such as SMED (Single-Minute Exchange of Die), becomes essential to address these problems and improve machine availability (Singh et al., 2018).

Addressing these production problems is crucial for the success and sustainability of food manufacturing SMEs. Improving machine availability not only increases operational efficiency but also contributes to cost reduction and product quality improvement (Randhawa & Ahuja, 2017). The implementation of Lean tools, such as 5S and TPM, can facilitate the creation of a more organized and efficient work environment, which in turn can lead to higher customer satisfaction and better competitiveness in the market (Randhawa & Ahuja, 2017). The literature suggests that adopting these methodologies can result in significant improvements in operational performance, which is especially relevant in a sector where quality and efficiency are paramount (Jiménez et al., 2019). Furthermore, the continuous improvement promoted by these methodologies can help SMEs adapt to changing market demands and consumer expectations (Domínguez et al., 2021).

Despite the abundant literature on Lean Manufacturing and TPM, there is a knowledge gap in the specific application of these methodologies in the context of food manufacturing SMEs in Latin America and Peru. Many studies have focused on large companies or different industrial sectors, leaving SMEs with little guidance on how to effectively implement these tools (Beske et al., 2014). This research aims to close this gap by developing a production model that integrates Lean tools, such as SMED, 5S, and autonomous maintenance, adapted to the particularities of the food sector (Jiménez et al., 2015). By providing a practical and accessible framework, this research is expected to not only benefit SMEs in terms of efficiency and productivity but also contribute to the development of a more sustainable and competitive food sector in the region (Batista et al., 2021).

In conclusion, the relevance of the food manufacturing SME sector is undeniable, and strengthening it is essential for economic development and food security. However, the production problems they face, such as low machine availability and lack of workplace order, require urgent attention. The implementation of Lean and TPM methodologies can offer effective solutions, but these tools need to be adapted to the specific context of SMEs in Latin America and Peru. This research seeks to contribute to this goal by providing a model that enables SMEs to improve their efficiency and competitiveness in an increasingly challenging environment.

2. Literature Review

2.1 Implementation of Lean Manufacturing in Food Producing SMEs

The implementation of continuous improvement methodologies in small and medium-sized enterprises (SMEs) producing food has gained relevance in recent literature, especially in the context of Lean Manufacturing. This methodology focuses on waste elimination and process optimization, resulting in a significant improvement in operational efficiency. According to Dora et al. (Dora et al., 2013), SMEs in the food sector have begun to adopt Lean Manufacturing practices, which have allowed them to reduce costs and improve profitability. However, despite the evident benefits, many of these companies have not yet fully capitalized on these advantages due to their early stage of adoption. Saboo et al.'s research (Saboo et al., 2014) highlights that a company's ability to effectively implement a continuous improvement philosophy is crucial for enhancing its operational performance. Furthermore, Steur et al. (Steur et al., 2016) suggest that value stream mapping can be an effective tool for identifying and reducing losses in food production, aligning with Lean Manufacturing principles. In this sense, the adoption of Lean Manufacturing practices not only results in operational improvements but can also contribute to the sustainability of the food sector, as mentioned in Ghosh's work (Ghosh, 2012), where manufacturing plants in India achieved superior operational performance by implementing these practices.

2.2 Application of the 5S Methodology in the Food Industry

The 5S methodology, which focuses on workplace organization and standardization, has proven to be a valuable tool for food-producing SMEs. This methodology not only improves operational efficiency but also promotes a safer and cleaner work environment. According to the research by Dora et al. (Dora et al., 2015), the implementation of 5S in food SMEs has led to a reduction in downtime and an improvement in product quality. Additionally, Ahmad et al.'s research (Ahmad et al., 2017) supports the idea that the application of 5S can facilitate the creation of a more efficient work environment, which in turn can lead to greater customer satisfaction. The importance of the 5S methodology is reinforced in the study by Psomas et al. (Psomas et al., 2018), which notes that SMEs that implement this methodology tend to experience significant improvements in their operational performance. However, despite these benefits, many SMEs face challenges in effectively implementing 5S, as discussed in the work of Driouach et al. (Driouach et al., 2019), where barriers that limit the adoption of these practices in the food sector are identified.

2.3 Reduction of Changeover Times through SMED in Food SMEs

The SMED (Single-Minute Exchange of Die) methodology has become a fundamental strategy for food-producing SMEs seeking to reduce changeover times and increase production flexibility. Kumar's research (Kumar, 2019) highlights that the implementation of SMED can result in a significant reduction in downtime, enabling companies to respond more quickly to market demands. Additionally, the study by Rao et al. (Rao et al., 2020) suggests that the application of SMED not only improves operational efficiency but also contributes to cost reduction, which is crucial for the sustainability of SMEs. In this context, Ghaithan et al.'s research (Ghaithan et al., 2021) shows that combining SMED with other Lean Manufacturing practices can lead to even more significant improvements in operational performance. However, the implementation of SMED in SMEs can face challenges such as a lack of training and resources, as mentioned in the work of Alcaráz et al. (Alcaráz et al., 2022), highlighting the need for a strategic approach to overcome these barriers.

2.4 Total Productive Maintenance (TPM) and Its Impact on Equipment Availability

The Total Productive Maintenance (TPM) methodology has emerged as a key strategy to improve the efficiency and effectiveness of operations in food-producing SMEs. According to the research by Ghaithan et al. (Ghaithan et al., 2023), the implementation of TPM can lead to a significant reduction in unplanned downtimes and an increase in equipment availability. Moreover, Vega et al.'s study (Vega et al., 2020) highlights that the adoption of TPM not only improves operational efficiency but also contributes to the enhancement of product quality, which is essential in the food industry. The research by Al-Jawazneh (Al-Jawazneh, 2015) also supports the idea that TPM implementation can result in an improvement in product quality, which in turn can increase customer satisfaction. However, the implementation of TPM in SMEs can be challenging, as discussed in the work of Dănuţ-Sorin et al. (Awwal, 2014), where barriers that limit the adoption of these practices in the food sector are identified. Therefore, it is crucial for SMEs to develop a strategic approach to overcome these challenges and maximize the benefits of TPM implementation.

2.5 Autonomous Maintenance: Empowering Operators in TPM

Autonomous Maintenance is a fundamental tool within the TPM framework that allows operators to take responsibility for the maintenance of their equipment. This methodology not only improves operational efficiency but also empowers employees by involving them in the maintenance process. According to Umasekar's research (Umasekar, 2024), the implementation of Autonomous Maintenance can lead to a significant reduction in downtime and an improvement in product quality. Additionally, the study by Aljunaidi and Ankrak (Aljunaidi & Ankrak, 2014) suggests that the adoption of Autonomous Maintenance can result in an increase in employee morale and their commitment to quality. However, the implementation of this methodology may face challenges such as a lack of training and resistance to change, as mentioned in the work of Dănuţ-Sorin et al. (Awwal, 2014). Therefore, it is essential for SMEs to develop effective strategies to overcome these barriers and maximize the benefits of Autonomous Maintenance implementation.

In conclusion, the implementation of continuous improvement methodologies such as Lean Manufacturing, 5S, SMED, TPM, and Autonomous Maintenance in food-producing SMEs can result in significant improvements in operational efficiency, product quality, and customer satisfaction. However, despite the evident benefits, many SMEs face challenges in implementing these practices. Therefore, it is crucial for SMEs to develop strategic approaches to overcome these barriers and maximize the benefits of these methodologies.

3. Methods

3.1 Basis of the Proposed Model

The model shown in Figure 1 illustrates the integration of Lean Manufacturing and Total Productive Maintenance (TPM) philosophies to increase the availability of milling machines in a small or medium-sized enterprise (SME) in the food industry. This approach aimed to address issues related to low availability rates through the implementation of key tools such as 5S, Single-Minute Exchange of Dies (SMED), and autonomous maintenance. The use of 5S helped standardize and optimize the work environment, ensuring a more efficient and organized space that reduced downtime and improved operational efficiency. Simultaneously, the application of SMED facilitated the reduction of setup and tool change times, directly impacting the improvement of machine availability by minimizing unplanned stops. Lastly, autonomous maintenance involved production personnel in basic maintenance tasks, which increased equipment reliability and, in turn, contributed to the increase in availability. Together, this model sought to elevate the availability of milling machines from low levels to a state of high availability, as graphically represented in Figure 1, thereby consolidating a significant improvement in the productive capacity of the company.

Figure 1. Proposed Model

3.2 Description of the model components

The proposed model, illustrated in the attached figure, represents an integrated solution based on the combination of Lean Manufacturing and Total Productive Maintenance (TPM) principles to improve the availability of milling machines in a small or medium-sized enterprise (SME) in the food industry. The implementation of this model is particularly relevant as it directly addresses one of the main issues faced by modern industrial organizations: the low availability of critical production equipment. By combining key tools, this approach not only increases operational capacity but also optimizes resource use and minimizes downtime. Below is a detailed, stage-by-stage description of the proposed model, highlighting the significance of each component within the context of a Lean-TPM strategy.

In the literature on operations management and process improvement, the combination of Lean Manufacturing and TPM has been recognized as an effective strategy to enhance equipment availability and efficiency in industrial plants. However, prior research has primarily focused on large-scale manufacturing sectors, leaving a gap in the analysis of its application in SMEs, particularly in industries such as food processing, where production equipment plays a central role. The model presented in this case study not only addresses this gap but also proposes a systematic structure that can be adapted to different sectors. Its design is based on waste reduction and maximizing machine performance, utilizing classic tools such as 5S, SMED, and autonomous maintenance, which are fundamental pillars of both Lean and TPM.

Implementation of the 5S Methodology

The first key component of the model is 5S, a set of principles aimed at maintaining a clean, organized, and efficient work environment. In this case, 5S was implemented in the milling area as the initial phase of the transformation towards a Lean-TPM model. During this phase, a comprehensive review of the workspace was conducted to eliminate unnecessary items and systematically organize tools and materials. The first S, Seiri (sort), involved identifying which elements were essential for daily operations and which could be discarded or relocated. This was followed by Seiton (set in order), in which tools were organized to be easily accessible, reducing downtime associated with searching for materials. Next, Seiso (shine) involved a deep cleaning of the machines and surrounding area, removing any residues that could affect the performance of the milling machines. This phase was crucial not only for improving the aesthetics and safety of the workspace but also for identifying potential mechanical failures caused by the accumulation of dirt. Seiketsu (standardize) consolidated the changes made by implementing visual controls and procedures to maintain order. Finally, Shitsuke (sustain) focused on establishing an organizational culture where maintaining a clean and orderly workspace became a daily routine.

The impact of this methodology was evident in the first few weeks of implementation, as it reduced operational interruptions caused by disorganization and significantly improved employee morale, who became actively involved in the process. Through greater shared responsibility, 5S created a solid foundation for integrating the subsequent phases of the model.

Reducing Setup Times with SMED
The second critical component of the model was the application of Single-Minute Exchange of Dies (SMED), a technique designed to drastically reduce tool change and machine setup times. In the case of the milling machines used by this company, changeover times represented a significant bottleneck, as every time configuration adjustments were needed, the machines had to be stopped for extended periods. SMED aimed to reduce these times to less than ten minutes, allowing for greater flexibility in production and a noticeable increase in machine availability.

To implement SMED, a detailed analysis of the tool change activities was conducted. These activities were categorized into two groups: internal tasks, which required the machine to be stopped, and external tasks, which could be performed while the machine was still running. Through the separation and optimization of these tasks, a significant reduction in changeover times was achieved. Additionally, technical improvements such as tool standardization and employee training in more agile procedures were introduced, which also contributed to improving efficiency in changeover operations. The introduction of SMED allowed the company to respond more quickly to changes in market demand, adjusting production lines without significantly affecting the availability of the milling machines.

Autonomous Maintenance as a Reliability Strategy
The final component of the model was the implementation of autonomous maintenance, one of the most representative strategies of TPM. This stage of the model aimed to empower production staff to take responsibility for performing basic maintenance tasks on the milling machines. The logic behind this strategy was based on the premise that those who operate the equipment daily are the most qualified to detect and prevent potential mechanical failures. Instead of relying solely on specialized maintenance staff, production personnel were trained to carry out tasks such as lubricating moving parts, cleaning critical components, and visually inspecting for possible wear or damage.

Autonomous maintenance significantly reduced unplanned downtime, as small issues were prevented from becoming major problems. Additionally, by involving operators in the care of the machines, a sense of ownership and responsibility over the equipment was fostered, which increased precision and care in their daily use. This strategy also resulted in fewer corrective interventions by the maintenance team, freeing up resources and time that were used for continuous improvement activities within the plant.

Together, the proposed Lean-TPM model was designed to increase the availability of milling machines through the application of continuous improvement tools and autonomous maintenance. Each component of the model, from the implementation of 5S to the use of SMED and the integration of autonomous maintenance, played a key role in achieving this objective. In Figure 1, the visual progression from a low availability rate to higher operational efficiency is shown, allowing the company not only to optimize resource use but also to improve its responsiveness to market demands. This model can be replicated in other SMEs in the food industry facing similar challenges, offering an adaptable and scalable solution for improving their industrial operations.

3.3 Model Indicators
To assess the impact of the production model integrating Lean and TPM tools, specialized metrics were developed to monitor and evaluate performance throughout the case study. These metrics provided a solid basis for analyzing critical aspects of the milling process in a food sector SME. This systematic approach facilitated a thorough review of key performance indicators, ensuring accurate monitoring and supporting continuous improvement in case study production processes.

Availability Rate:
This indicator measures the proportion of time the machine was available for production compared to the total operational time.

$$\text{Availability} = \left(\frac{\text{Operating Time}}{\text{Scheduled Time}}\right) \times \mathbf{100} \tag{1}$$

MTTR (Mean Time to Repair):
MTTR calculates the average time taken to repair a machine after a failure. Lower MTTR indicates quicker repair times.

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Number of Repairs}} \tag{2}$$

MTBF (Mean Time Between Failures):
MTBF measures the average time between equipment breakdowns, reflecting machine reliability.

$$\text{MTBF} = \frac{\text{Total Operating Time}}{\text{Number of Failures}} \tag{3}$$

Setup Time:
This indicator represents the time taken to prepare a machine for production, including changeovers and adjustments.

$$\text{Setup Time} = \text{Total Time Spent on Setup Activities} \tag{4}$$

Number of Faults:
This measures the total number of machine failures during a specified time period, indicating operational disruptions.

$$\boldsymbol{No\ formula\ is\ required\ as\ this\ is\ a\ direct\ count.} \tag{5}$$

4. Validation

4.1 Validation Scenario

The validation scenario was conducted in a case study of an agricultural production company specializing in the manufacturing of protein flours derived from animal by-products through the process known as rendering. The company, which had been in the sector for over 10 years, faced challenges in maintaining adequate equipment availability, particularly in the milling process, which had a reported availability rate of 77.01%. This figure fell below the industry standard of 80%, signaling inefficiencies linked to frequent machine stoppages, lengthy setup times, and a lack of order and cleanliness in the production area. As a result, the company implemented Lean Manufacturing tools such as 5S, SMED, and autonomous maintenance to address the root causes of these issues. The objective was to increase the availability rate by at least 5%, optimize machine reliability, and improve overall production efficiency through systematic process improvements.

4.2 Initial Diagnosis

In Figure 2, the problem tree summarizes the diagnostic performed in the case study to identify the main reasons and root causes of low availability in the milling process. The identified technical problem was an availability rate of 77.01%, which is below the industry standard of 80%, resulting in an estimated economic impact of 1,175,472 PEN per year, representing 2% of the company's annual revenue. At Level 1 of the analysis, the primary causes were identified as high unproductive times (75%) and frequent operator failures (25%). At Level 2, the root causes of unproductive times were mainly attributed to high machine shutdowns due to failure (45.98%) and frequent setup stops (29.02%). On the other hand, operator failures were linked to a lack of order and cleanliness in the facility (21%). This analysis helped to pinpoint the critical factors affecting process availability, providing a strong foundation for the intervention of Lean-TPM tools, such as autonomous maintenance and the 5S methodology, aimed at mitigating root causes and improving operational efficiency.

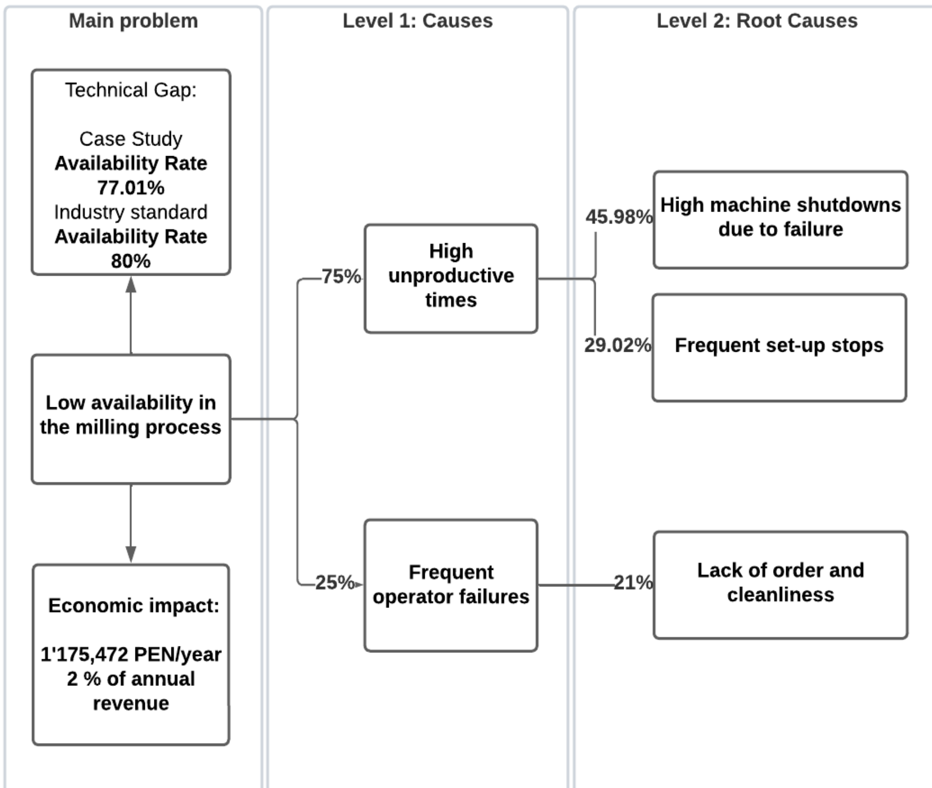

Figure 2. Problem Tree

4.3 Implementation of the model in the case study

The proposed model's implementation in the case study focused on improving the milling process in a company that produces protein flours. Lean Manufacturing tools were applied to increase process availability, addressing root causes that hindered efficiency. The design of the solution involved the application of 5S, SMED, and autonomous maintenance tools in a structured sequence to ensure significant operational improvements. The detailed design of the solution is presented in the following subsections, with each methodology aiming to tackle specific inefficiencies within the milling process.

Workplace Optimization through 5S

The implementation of the 5S methodology sought to optimize workplace organization and cleanliness, which were identified as key factors contributing to downtime and operational inefficiencies. Initially, the team conducted a Seiri phase (Sorting), where unnecessary items and tools were removed from the workspace. This step helped eliminate obstacles that contributed to workflow interruptions. The Seiton (Set in Order) phase followed, where essential tools and materials were systematically arranged in designated areas, ensuring ease of access and reducing time lost searching for items. Specific zones were allocated for storage of essential tools and containers, as well as designated areas for waste disposal, enhancing spatial efficiency.

In the Seiso (Shine) phase, cleaning kits were distributed across work areas, specifically designed for the distinct needs of machines and manual workspaces. These kits included industrial cleaning materials such as brooms, industrial cloths, and lubricants for equipment. Establishing a Seiketsu (Standardize) plan was crucial for maintaining cleanliness and order. The plan detailed regular cleaning schedules and inspection routines to ensure that equipment and work areas were consistently maintained in optimal condition. A final Shitsuke (Sustain) step introduced regular meetings and audits to reinforce the 5S principles and ensure continued compliance with cleanliness and organizational standards. As a result, disorder in the workspace was reduced from an initial 66.67% to a notable 29.33%, enhancing both operational flow and employee morale.

In Figure 3, the distribution of the general cleaning kits implemented in the workplace is shown as part of the third S, Seiso (Cleanliness), from the 5S method. These kits are divided into two main categories: the General Cleaning Kit, which includes items such as brooms, dustpans, industrial cloths, cleaning gloves, and trash bags, and the Specialized Cleaning Kit, containing lubricants, mops, scrub brushes, and paint brushes. This organization of the kits was implemented to facilitate cleaning and maintenance tasks in the workspace, ensuring immediate access to necessary materials for keeping the area in optimal condition, thus promoting a safer and more efficient environment.

Figure 3. General cleaning kits

Reducing Changeover Times with SMED

The SMED (Single-Minute Exchange of Die) methodology was implemented to address the excessive setup times in the milling process. The team conducted a thorough analysis of the setup activities, categorizing them as either internal (requiring equipment shutdown) or external (performed while machines remain operational). Through this analysis, several internal activities were converted into external tasks, allowing these procedures to be performed without stopping the equipment. As a result, the total setup time decreased from 301.28 minutes to 210.02 minutes, representing a 30.81% improvement.

Training sessions were conducted for the operating personnel to ensure they were equipped with the skills and knowledge to perform quick and effective changeovers. This training was delivered through seminars held at the beginning of each workday, where visual presentations and hands-on demonstrations were used to explain the newly established setup procedures. By standardizing these processes, the company was able to significantly reduce downtime associated with setup, increasing overall flexibility and responsiveness to production demands. This improvement directly contributed to the company's goal of increasing equipment availability, as shorter setup times translated into longer operational periods.

In Figure 4, the application of improvements to new internal and external activities is shown as part of the implementation of the SMED (Single-Minute Exchange of Die) tool. The table highlights the times before and after the SMED application, categorizing each task into internal or external activities. Before the SMED implementation, several tasks, such as stopping the operation of the dosing pump, removing the air injector, or cleaning the dosing pump nozzle, were carried out internally, leading to significant downtime. After the SMED application, some of these tasks were converted into external activities, meaning they could be done without halting the equipment, thus improving operational efficiency.

For example, activities like cleaning tools and preparing materials for maintenance were shifted from internal tasks that required machinery stoppage to external tasks that could be performed while the equipment was still running. The total time for internal activities was reduced from 301.28 minutes to 225.21 minutes, representing a 25.63% reduction in downtime, while external tasks remained stable or were improved slightly.

The table also outlines improvement actions for each task, such as training operators in format changeover processes or creating designated zones for materials and tools, all aimed at further reducing times and increasing flexibility. This structured approach underlines the efficiency gains from converting internal activities into external ones, a key goal of SMED.

N°	Actividad	Tiempo antes de la aplicación (min)	Actual		Tiempo después de la aplicación (min)	Después		Acción de mejora	Responsable
			Interno	Externo		Interno	Externo		
1	Detener operación de la bomba dosificadora del molino	0.33	x		0.33	x			
2	Desenroscar la boquilla del aplicador	1.53	x		1.53	x			
3	Traer inyectora de aire	2.30	x		0.00		x	Se preparó una zona cerca de la molienda donde se encuentren todas los accesorios y herramientas para el cambio de formato	Jefe de mantenimiento
4	Limpiar la boquilla de la bomba dosificadora	3.00	x		2.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
5	Secar la boquilla de la bomba dosificadora	2.42	x		2.30	x			
6	Reinstalar la boquilla al dosificador	1.50	x		1.50	x			
7	Encender el ducto de asistencia	0.70		x	0.70		x		
8	Esperar que salga las harina suelta	3.20		x	3.20		x		
9	Apagar y bloquear el equipo	2.18	x		2.00	x			
10	Abrir escotilla de acceso al nivel de las tuberías	1.87	x		1.50	x			
11	Traer los materiales para la limpieza	2.10	x		0.00		x	Se preparó una zona cerca de la molienda donde se encuentren todas los accesorios y herramientas para el cambio de formato	Jefe de mantenimiento
12	Aplicar golpes leves dentro de las tuberías	5.93	x		5.00	x			
13	Limpiar por dentro de las tuberías	7.67	x		7.67	x			
14	Cerrar escotillas del sistema herméticamente	3.88	x		3.20	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
15	Destapar tapa superior de la chumacera	1.67	x		1.67	x			
16	Traer lubricante al área del molino	2.21	x		0.00		x	Se preparó una zona cerca de la molienda donde se encuentren todas los accesorios y herramientas para el cambio de formato	Jefe de mantenimiento
17	Retirar la grasa quemada del rodamiento y de la chumaceras	9.13	x		7.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
18	Lubircar el compartimiento de las chumaceras	6.62	x		6.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
19	Esperar y verificar que el aceite desborde de la	5.42	x		5.42	x			
20	Colocar tapa superior de la chumacera	2.17	x		2.17	x			
21	Retirar martillos del molino	24.84	x		24.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
22	Limpiar los martillos extraídos	8.08	x		8.08		x		
23	Identificar las zonas de los martillos desgastados	7.08	x		7.08		x		
24	Rellenar los martillos mediante soldadura	72.17		x	72.17		x		
25	Revisar que cada martillo pese 1 Kg	23.13	x		23.13		x		
26	Suavizar los bordes	12.83	x		12.83		x		
27	Ingresar martillos al molino	23.90	x		23.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
28	Abrir la caja del motor	2.37	x		2.00	x			
29	Retirar la grasa quemada del rodamiento y de la chumaceras	7.00	x		7.00	x			
30	Aplicar lubricante a la gracera de la chumaceras del motor	5.90	x		5.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
31	Esperar y verificar que el aceite desborde de la gracera	5.33	x		5.33	x			
32	Cerrar caja del motor	2.03	x		2.03	x			
33	Colocar cribas según el producto solicitado	19.00	x		17.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
34	Colocar malla de zaranda según el producto solicitado	20.70	x		18.00	x		Capacitar al operario para el apoyo del cambio de formato	Supervisor
35	Encender molienda	1.08	x		1.08	x			
	Total	301.28	225.21	76.07	280.92	153.73	127.19		
		57.73							
		25.63%							

Figure 4. Implementation of improvement in new external and internal activities

Improving Equipment Availability with Autonomous Maintenance

The implementation of autonomous maintenance aimed to empower operators to take responsibility for the upkeep of their equipment, thus enhancing both equipment reliability and overall availability. The first step involved a comprehensive cleaning and inspection phase, where workers were trained to identify potential abnormalities such as wear and tear, corrosion, or misalignments. A standardized inspection format was introduced, enabling operators to check key components like hammers, screens, and bearings, and promptly report any issues.

Subsequent steps focused on eliminating sources of contamination and improving access to hard-to-reach areas of the equipment, ensuring that cleaning and lubrication tasks could be performed efficiently. Operators were also trained in the use of PDCA (Plan-Do-Check-Act) cycles to refine cleaning and lubrication procedures. By systematically planning and improving these maintenance activities, the team was able to ensure that machinery remained in optimal condition, thus preventing unexpected breakdowns.

In addition to regular inspections, operators were encouraged to conduct autonomous inspections, fostering a sense of ownership and responsibility over their machinery. A visual management system was introduced using color-coded tags to highlight any operational, maintenance, or safety concerns. For instance, blue tags indicated operational issues, orange tags highlighted maintenance needs, and yellow tags were used to flag potential safety hazards. This system ensured that all potential issues were addressed in a timely manner, reducing the likelihood of equipment failure.

The results of the autonomous maintenance program were significant. The mean time to repair (MTTR) was reduced from 2.36 hours to 1.84 hours, reflecting a 43.96% improvement. Similarly, the mean time between failures (MTBF) increased from 27.27 hours to 39.30 hours, indicating a substantial enhancement in equipment reliability. These improvements translated into an overall increase in equipment availability, which rose from 77.01% to 82%, surpassing the target of 80%.

Comprehensive Application of Lean Tools for Sustainable Improvements

The integration of Lean Manufacturing tools, particularly 5S, SMED, and autonomous maintenance, provided a robust framework for addressing the root causes of inefficiency in the milling process. The 5S methodology contributed to a more organized and cleaner workspace, significantly reducing the risk of operational interruptions caused by disorganization and clutter. SMED helped streamline the setup process, allowing for quicker transitions between production runs and reducing equipment downtime. Autonomous maintenance empowered operators to take proactive roles in equipment care, resulting in improved reliability and extended operational periods between breakdowns.

The success of these interventions is evident in the key performance indicators. Equipment availability increased by 5%, reaching 82%, while MTBF rose by 44% to 39.30 hours. Additionally, setup times were reduced by 30%, and disorder in the work area decreased by more than half. These improvements not only enhanced operational efficiency but also contributed to cost reductions and improved product quality, positioning the company to better meet market demands.

5. Results

In Table 1, the validation of the proposed Lean-TPM production model shows key improvements in operational performance. Machine availability increased by 6.48%, while the Mean Time to Repair (MTTR) was reduced by 22.03%. The Mean Time Between Failures (MTBF) rose by 44.33%, reflecting better machine reliability. Additionally, setup time was reduced by 30.81%, and the number of faults decreased by 27.98%, confirming the model's effectiveness in enhancing availability and reducing downtime.

Table 1. Results of validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Availability Rate	%	77.01%	90%	82.00%	6.48%
MTTR (Average repair time)	minute	2.36	1.5	1.84	-22.03%
MTBF (Mean time between failures)	minute	27.23	45	39.3	44.33%
Time to set up	minute	303.54	195	210.02	-30.81%
Number of faults	times	243	120	175	-27.98%

6. Conclusions

The main findings of this study highlight the successful application of Lean Manufacturing and Total Productive Maintenance (TPM) tools in improving operational efficiency within a small Peruvian food processing company. The implementation of 5S, SMED, and autonomous maintenance had a measurable impact on machine availability, setup times, and the overall effectiveness of the production process. Specifically, machine availability increased from 77.01%

to 82%, setup times were reduced by 30.81%, and machine downtime due to unplanned failures decreased substantially. These results demonstrate the effectiveness of Lean and TPM methodologies in addressing the critical challenges that small and medium-sized enterprises (SMEs) in the food sector often face, particularly in terms of operational inefficiencies and equipment reliability.

The importance of this research lies in its ability to provide actionable insights for SMEs in Latin America, a sector where production efficiency and sustainability are paramount. SMEs are vital for food security and economic stability in the region, yet they face persistent operational challenges, including high downtime and inefficient processes. This study confirms that integrating Lean and TPM tools can directly address these challenges by optimizing production processes and enhancing equipment reliability, thus contributing to greater competitiveness and sustainability in the industry. The research's emphasis on practical solutions for reducing inefficiencies offers valuable lessons for other SMEs facing similar issues.

This study contributes to the broader field of Industrial Engineering by offering a replicable model for integrating Lean and TPM tools in small-scale food processing industries. While previous research has extensively covered the application of these methodologies in large enterprises, this study fills a gap by focusing on SMEs in the food sector, particularly in developing countries. The research highlights the importance of adapting Lean and TPM strategies to the unique challenges faced by smaller companies, such as limited resources and workforce capacity. By demonstrating how to implement these tools effectively in resource-constrained environments, the study provides a framework that can be adapted and applied in similar contexts worldwide.

The final observations of this research suggest that the implementation of Lean Manufacturing and TPM tools not only improves operational efficiency but also fosters a culture of continuous improvement within the organization. Employees became more engaged in maintaining the equipment and following standardized procedures, which contributed to sustained improvements in both machine reliability and product quality. These findings underscore the potential long-term benefits of embedding Lean and TPM methodologies into the organizational culture, ensuring that improvements are sustained over time.

Future research should explore additional applications of Lean and TPM tools in other sectors of the food industry, with a particular focus on the integration of digital technologies such as Industry 4.0. There is also a need to investigate the long-term sustainability of these interventions, particularly in how they contribute to environmental goals and resource optimization. Furthermore, future studies could analyze the scalability of the model developed in this research, determining its applicability to other regions and sectors. This would provide a more comprehensive understanding of how Lean and TPM methodologies can be leveraged to enhance both operational performance and sustainability across a variety of industries.

In conclusion, this study provides compelling evidence that Lean Manufacturing and TPM tools are highly effective in improving operational performance in SMEs within the food sector. By addressing machine downtime, setup times, and maintenance practices, the company not only achieved greater efficiency but also set a foundation for long-term sustainability. This research offers a clear roadmap for other SMEs in the region to follow, emphasizing the need for a strategic and well-structured approach to process improvement. As industries face increasing pressure to optimize both economic and environmental performance, this study serves as a timely and valuable contribution to the field, encouraging further exploration of Lean and TPM applications in diverse industrial settings..

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