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Integrating Lean Manufacturing and TPM for Process Optimization in Bakery SMEs: A Case Study from Peru

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Abstract

The bakery SME sector in Latin America, particularly in Peru, plays a critical role in food security and local economic development but faces significant inefficiencies in production, equipment downtime, and inconsistent product quality. Despite the potential of Lean Manufacturing and Total Productive Maintenance (TPM) to mitigate these challenges, their application in the bakery sector remains underexplored. This study implemented 5S, work standardization, and autonomous maintenance in a bakery SME to reduce delays, equipment failures, and defects. The approach focused on optimizing operations, enhancing equipment reliability, and promoting continuous improvement. The key results included a 70% improvement in workplace organization and cleanliness, a 60% reduction in defective products, and a 35% decrease in machine repair time, demonstrating the efficacy of Lean and TPM tools. The research offers a replicable model for bakery SMEs, contributing to operational efficiency and product quality improvements, which are crucial for regional economic development. Further exploration of Lean and TPM integration in SMEs is essential to foster innovative solutions to industry challenges.

Keywords

Lean Manufacturing, Total Productive Maintenance, Bakery SMEs, Process Optimization, 5S.

1. Introduction

The small and medium-sized enterprises (SMEs) in the bakery sector play a critical role in the global economy, particularly in Latin America and Peru. This sector not only significantly contributes to employment and income for many families but also is essential for food security and cultural diversity through the production of a wide range of baked goods. In Latin America, SMEs account for approximately 99% of all businesses, and in Peru, this percentage is even higher, having a notable impact on local economic development Baregheh et al. (2012). The bakery industry, in particular, has demonstrated consistent growth, driven by the demand for fresh and quality products (Le et al. 2023). However, despite its importance, SMEs in the bakery sector face significant challenges that limit their ability to operate efficiently and competitively in an increasingly demanding market.

Production problems within SMEs in the bakery sector are varied and complex, primarily related to the failure to meet product delivery timelines, which adversely affects customer satisfaction and the company's reputation. Additionally, excessive unproductive time has become a central concern, as many companies have not implemented adequate

methodologies to optimize their processes. Inefficient searching for tools and inadequate maintenance of machinery contribute to the generation of defective products, which in turn increases operational costs and reduces profitability. The lack of standardization in work methods also plays a critical role, as without clear procedures, employees may make mistakes that affect the final product's quality. Therefore, it is evident that improving production processes is essential to address these deficiencies and ensure the sustainability of SMEs in the bakery sector.

Addressing these problems is of utmost importance for the bakery SMEs sector, as it not only impacts operational efficiency but also has repercussions on competitiveness and the ability of companies to adapt to market demands. The implementation of methodologies such as Lean Manufacturing and Total Productive Maintenance (TPM) can provide effective solutions to optimize production processes, reduce waste, and improve product quality. These tools not only help identify and eliminate inefficiencies but also promote a culture of continuous improvement that is vital for long-term growth. Therefore, tackling these issues is beneficial not only for individual companies but also contributes to the broader economic development of the region.Despite the relevance of these topics, there exists a significant gap in the literature regarding the application of Lean Manufacturing and TPM tools in the context of bakery SMEs in Latin America, and specifically in Peru. This research aims to fill this gap by developing a production model that integrates these methodologies, focusing on tools such as 5S and work standardization. By doing so, it is expected to not only improve efficiency and quality in production but also provide a practical framework that other bakery SMEs can adopt to address their own challenges. This approach is not only innovative but also necessary to ensure that bakery SMEs can compete in an increasingly challenging global market.

In conclusion, the bakery SMEs sector is a vital industry that faces numerous challenges requiring urgent attention. The implementation of appropriate methodologies can transform these problems into opportunities, and research in this field is essential to provide the necessary tools for success. The integration of Lean Manufacturing and TPM in bakery SMEs will not only enhance operational efficiency but also contribute to the sustainable development of the local and regional economy.

2. Literature Review

2.1 Application of Lean Manufacturing in Bakery SMEs

The implementation of Lean Manufacturing methodologies in small and medium-sized enterprises (SMEs), particularly in the bakery sector, has garnered significant attention in recent research. Lean Manufacturing focuses on minimizing waste while maximizing productivity, which is particularly beneficial for SMEs that often operate with limited resources. According to (Dora et al. 2013), the application of Lean practices in small and medium-sized food enterprises has led to substantial improvements in operational efficiency and product quality. This study emphasizes that Lean methodologies are not exclusive to large corporations; rather, they can be adapted to fit the unique needs and constraints of SMEs, where flexibility and rapid adaptation are essential. Inuwa & Usman (2022) further support this notion, indicating that Nigerian SMEs exhibit organizational flexibility that facilitates the adoption of Lean practices, although they also encounter challenges that can impede successful implementation. Moreover, Agrawal et al. (2017) utilize fuzzy logic to evaluate the "leanness" of an Indian SME, highlighting the importance of continuous assessment in ensuring effective Lean implementation. Finally, Castro & Posada (2019) provide a case study from Medellín, demonstrating that the integration of Lean techniques in the bakery industry resulted in significant enhancements in operational efficiency and customer satisfaction.

2.2 Implementation of Total Productive Maintenance in Bakery SMEs

Total Productive Maintenance (TPM) is another methodology that has shown promise in enhancing operational efficiency within bakery SMEs. Valente et al. (2019) assert that the adoption of TPM in small and medium-sized enterprises not only improves equipment availability but also boosts employee morale, fostering a more positive work environment. Hu et al. (2015) conducted a comprehensive literature review on TPM implementation in SMEs, identifying employee training and engagement as critical factors for successful adoption. Their findings suggest that when employees are actively involved in maintenance processes, the overall performance of the organization improves. Additionally, Abdallah et al. (2021) conclude that integrating TPM with process and management innovations can yield significant operational performance improvements in the food industry. Sahoo & Yadav (2018) emphasize that TPM goes beyond merely reducing downtime; it also cultivates a culture of continuous improvement, which is vital for the long-term sustainability of SMEs.

2.3 Application of the 5S Methodology in Bakery SMEs

The 5S methodology, which emphasizes workplace organization and standardization, has been effectively implemented in various bakery SMEs. Psomas et al. (2018) indicate that the adoption of 5S in small and medium-sized food enterprises in Greece has led to notable improvements in operational efficiency and waste reduction. This methodology not only enhances physical organization but also contributes to a safer and more efficient work environment. Dresch et al. (2019) further support this by noting that the implementation of 5S in Brazilian SMEs has resulted in increased productivity and reduced operational costs. Yamchello et al. (2014) highlight the importance of prioritizing Lean practices, such as 5S, within SMEs, suggesting that these practices can be pivotal for a company's success. Finally, Knol et al. (2018) demonstrates that the implementation of 5S not only enhances efficiency but also fosters a stronger and more committed organizational culture.

2.4 Standardization of Work in Bakery SMEs

Work standardization is a crucial aspect of process improvement in bakery SMEs. Ramadas & Satish (2018) assert that standardization enables organizations to establish clear procedures, facilitating the training of new employees and ensuring consistency in production. Battistoni et al. (2013) further argue that standardization enhances product quality and reduces production time by eliminating unnecessary variations. In the context of SMEs, Knapić et al. (2022) emphasize that employee involvement in developing work standards is essential for their acceptance and success. Cocca & Alberti (2010) stress that work standardization must be an ongoing process, requiring companies to regularly review and adjust their procedures to adapt to changing market demands.

2.5 Autonomous Maintenance in Bakery SMEs

Autonomous maintenance empowers employees to take responsibility for the upkeep of their equipment, which can be particularly beneficial in bakery SMEs. Lee (2022) indicates that the implementation of autonomous maintenance in the manufacturing sector has been shown to improve operational efficiency and reduce maintenance costs. Burawat (2019) suggests that transformational leadership is crucial for the successful implementation of autonomous maintenance, as it creates an environment where employees feel valued and motivated to participate. Dora et al. (2015) also highlight that autonomous maintenance enhances equipment availability and contributes to a culture of continuous improvement. Taj & Morosan (2011) emphasize that autonomous maintenance can serve as a competitive differentiator for SMEs, enabling them to swiftly adapt to changes in market demand.

3. Methods

3.1 Basis of the Proposed Model

In Figure 1, the production model based on the Lean Manufacturing philosophy and Total Productive Maintenance (TPM) for small and medium-sized bakeries is presented. This model combined the principles of Lean and TPM to optimize operational efficiency, reduce waste, and improve equipment reliability. The Lean component, focusing on the 5S methodology, aimed to create a standardized and organized work environment by promoting sorting, setting in order, shining, standardizing, and sustaining practices across workstations. This helped in reducing inefficiencies related to disorganization and variability in processes. On the other hand, the TPM philosophy emphasized proactive and preventive maintenance, aiming to ensure that equipment operated at peak performance with minimal downtime. The autonomous maintenance aspect empowered workers to take responsibility for the routine maintenance of their machines, further contributing to operational reliability. The ultimate goal of this integrated Lean-TPM model was to establish a production system that minimized defects, reduced delays, and maximized equipment availability, thereby enhancing the overall productivity and competitiveness of bakeries in the sector. The model fostered a culture of continuous improvement, enabling bakeries to consistently deliver high-quality products and meet customer demands efficiently.

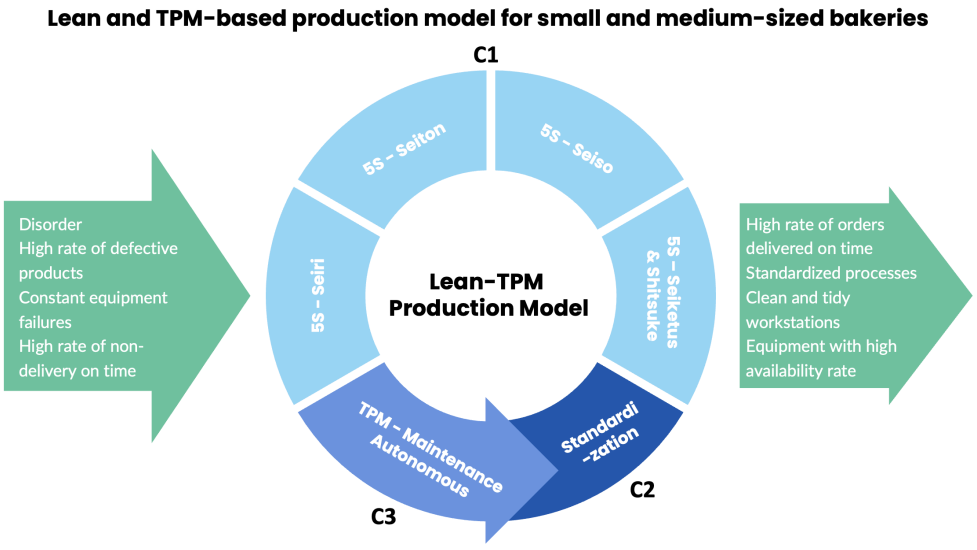

Figure 1.Proposed Model

3.2 Description of the model components

The proposed production model based on Lean Manufacturing and Total Productive Maintenance (TPM) for small and medium-sized bakeries contributes significantly to the existing literature on operational efficiency and process optimization. Lean Manufacturing, which emphasizes waste reduction and value creation, has been widely applied in various industries to streamline processes and eliminate inefficiencies (Womack & Jones 1996). The integration of TPM, which focuses on maximizing equipment effectiveness through autonomous maintenance and continuous improvement, adds a critical layer to the operational model, especially for industries where machinery plays a pivotal role in production (Nakajima 1988). Together, these two philosophies provide a comprehensive framework for small and medium-sized enterprises (SMEs) in the bakery sector, aiming to address challenges such as equipment downtime, process variability, and production delays. The proposed model fills a gap in the existing literature by offering a sector-specific solution that addresses the unique operational challenges of bakeries. By integrating Lean's focus on process efficiency with TPM's emphasis on equipment reliability, this model offers a holistic approach to improving both product quality and operational performance.

***S*orting and Organization (5S - Seiri)**

The first stage of the model is based on the Lean Manufacturing principle of 5S, specifically focusing on Seiri or sorting. This stage was crucial for identifying and categorizing all materials, tools, and equipment used in the bakery's production process. Items that were not necessary for daily operations were systematically removed from the workspace to prevent clutter and confusion, leading to a more streamlined workflow. The process of sorting not only improved the organization of the workspace but also allowed for a clearer understanding of what resources were available and in use at any given time. Previous studies have highlighted the importance of workplace organization in enhancing productivity and reducing waste (Belekoukias et al. 2014). In the case of this bakery model, sorting was fundamental in establishing a baseline for operational efficiency by removing unnecessary items and ensuring that only essential tools and materials remained in the production environment. This step contributed to reduced search times and fewer interruptions in the production process.

Setting in Order (5S - Seiton)

After sorting, the next phase of the model involved Seiton, or setting items in order. This Lean principle aimed to optimize the layout of the workspace by ensuring that tools, materials, and equipment were positioned logically and within easy reach of workers. In the context of a bakery, this meant arranging ingredients, baking tools, and machinery in a way that minimized movement and reduced the time spent searching for necessary items. The efficient arrangement of the workspace contributed to a smoother workflow, as employees could access what they needed without unnecessary delays. Research has shown that setting items in order is particularly effective in reducing lead times and improving overall process efficiency (Shah & Ward 2003). By standardizing the placement of tools and

materials, the bakery was able to reduce the time spent on non-value-added activities, such as walking across the workspace to retrieve tools, thus enhancing operational performance.

Shining and Cleaning (5S - Seiso)
The third stage, Seiso or shining, emphasized the importance of cleanliness in maintaining an efficient production environment. In the bakery sector, where hygiene is paramount, maintaining a clean workspace was not only essential for product quality but also for operational efficiency. The implementation of a daily cleaning routine ensured that all workstations, machinery, and tools were kept in optimal condition. Cleanliness contributed to the early detection of potential equipment malfunctions, as issues such as wear, and tear or leaks were more easily identified in a clean environment. Studies on Lean implementations in food production have underscored the role of cleanliness in preventing production delays and equipment breakdowns (Arbulu & Zabelle 2006). In this model, the regular cleaning and maintenance of workstations and equipment helped reduce the occurrence of breakdowns, leading to higher productivity and less downtime.

Standardizing Practices (5S - Seiketsu)
The next component, Seiketsu, focused on standardizing the practices developed in the previous stages. Standardization is a key tenet of Lean Manufacturing, as it ensures that the improvements made through sorting, organizing, and cleaning are consistently applied across the organization. In the bakery model, this involved developing clear protocols for daily operations, including the handling of ingredients, the operation of machinery, and the cleaning of workstations. Standard operating procedures (SOPs) were created to guide employees through each step of the production process, ensuring consistency in quality and efficiency. According to Liker (2004), standardization is critical for sustaining Lean improvements, as it creates a stable foundation for continuous improvement. By establishing clear standards, the bakery was able to reduce process variability and ensure that all workers followed the same best practices, contributing to a more predictable and efficient production process.

Sustaining Improvements (5S - Shitsuke)
The final stage of the 5S process, Shitsuke or sustaining, was centered on maintaining the improvements achieved in the earlier stages. This component was particularly important for ensuring the long-term success of the Lean-TPM model. Sustaining involved regular audits, employee training, and continuous improvement initiatives to ensure that the standards set during the previous phases were adhered to over time. The bakery established a system of periodic reviews to monitor compliance with the 5S practices and to identify any areas where further improvements could be made. Employee engagement played a crucial role in sustaining these improvements, as workers were encouraged to take ownership of their workstations and actively participate in continuous improvement efforts. As noted by Bhasin and Burcher (2006), sustaining Lean improvements requires a cultural shift within the organization, where employees are fully committed to maintaining the standards and continuously seeking ways to improve. In this case, sustaining the 5S practices helped the bakery maintain high levels of operational efficiency and prevent the reemergence of old inefficiencies.

Autonomous Maintenance (TPM)
The integration of TPM into the production model began with autonomous maintenance, a core pillar of TPM that empowers employees to take responsibility for the routine maintenance of their equipment. In the bakery, this meant training workers to perform basic maintenance tasks, such as cleaning, lubricating, and inspecting machinery, without needing specialized maintenance personnel. Autonomous maintenance not only reduced equipment downtime but also increased employee engagement, as workers became more attuned to the condition of their machinery and were able to identify potential issues before they escalated into major problems. Nakajima (1988) emphasized the importance of autonomous maintenance in TPM, noting that it fosters a sense of ownership among employees and leads to higher equipment availability. In this bakery model, the implementation of autonomous maintenance contributed to a significant reduction in equipment breakdowns and an increase in overall equipment effectiveness (OEE).

Standardizing Maintenance Practices (TPM - Standardization)
Similar to the standardization of production practices, the bakery also standardized its maintenance procedures to ensure consistency in equipment care. This involved developing maintenance schedules, checklists, and protocols that outlined the steps workers should follow when performing routine maintenance tasks. The standardization of maintenance practices helped ensure that all equipment received the necessary care at regular intervals, reducing the likelihood of unexpected breakdowns. Additionally, standardized maintenance procedures allowed for more accurate tracking of maintenance activities and equipment performance, enabling the bakery to identify trends and potential

areas for improvement. Research has shown that standardizing maintenance practices is essential for sustaining the benefits of TPM and ensuring long-term equipment reliability (Shirose, 1992). In this model, the standardization of maintenance practices played a key role in maintaining high levels of equipment availability and minimizing production interruptions.

Continuous Improvement (Kaizen)

The final component of the Lean-TPM production model was the continuous improvement (Kaizen) philosophy, which encouraged workers at all levels of the bakery to regularly seek out opportunities for incremental improvements. Kaizen is a core principle of both Lean Manufacturing and TPM, emphasizing small, continuous changes that lead to significant long-term improvements in productivity and quality. In the bakery, Kaizen initiatives included regular team meetings to discuss potential improvements, as well as the implementation of employee suggestions for process enhancements. By fostering a culture of continuous improvement, the bakery was able to sustain its Lean and TPM practices over time, ensuring that operational efficiency and equipment reliability continued to improve. Kaizen has been widely recognized as a critical factor in the success of Lean and TPM implementations, as it promotes a proactive approach to problem-solving and empowers employees to take an active role in the improvement process (Imai, 1986). In this bakery model, the application of Kaizen helped create a dynamic and adaptable production system that continuously evolved to meet the demands of the business.

3.3 Model Indicators

To assess the impact of the Lean Manufacturing and TPM-based production model for small and medium-sized bakeries, specialized metrics were developed to accurately monitor and evaluate performance throughout the case study. These metrics provided a structured framework for analyzing critical aspects of production management within the SME bakery environment. This systematic approach allowed for a thorough examination of key performance indicators, offering insights into operational efficiency and areas for improvement. The comprehensive evaluation ensured effective monitoring and facilitated continuous improvement of storage and production processes. Ultimately, this contributed significantly to reducing the product delivery failure rate within the bakery SME, enhancing overall operational performance and service reliability.

Rate of Fulfillment of Orders: This indicator measures the percentage of orders delivered on time as requested by the customer. It reflects the operational efficiency and reliability of the company's delivery process.

$$\text{Rate of Fulfillment} = \left(\frac{\text{Orders Delivered On Time}}{\text{Total Orders}}\right) \times 100 \quad (1)$$

5S Audit: This indicator measures the compliance level with the 5S methodology. It evaluates the efficiency of workspace organization, cleanliness, and standardization practices.

$$\text{5S Audit Score} = \left(\frac{\text{5S Compliant Areas}}{\text{Total Audited Areas}}\right) \times \mathbf{100} \quad (2)$$

Time Spent Searching for Materials: This indicator represents the average time in minutes that workers spend locating materials or tools, reflecting the efficiency of organization within the workspace.

$$\text{Time Spent Searching} = \frac{\text{Total Time Spent}}{\text{Number of Searches}} \tag{3}$$

Rate of Reprocessed Products: This indicator measures the percentage of products that required reprocessing due to defects or quality issues. It reflects the overall product quality and manufacturing process reliability.

$$\text{Rate of Reprocessing} = \left(\frac{\text{Reprocessed Products}}{\text{Total Products}}\right) \times \mathbf{100} \tag{4}$$

MTBF (Mean Time Between Failures): This indicator calculates the average time in hours between two consecutive failures of equipment or machinery, reflecting reliability.

$$\text{MTBF} = \frac{\text{Total Operating Time}}{\text{Number of Failures}} \tag{5}$$

MTTR (Mean Time to Repair): This indicator measures the average time in hours required to repair machinery or equipment after a failure, indicating the effectiveness of the maintenance process.

$$\text{MTTR} = \frac{\text{Total Repair Time}}{\text{Number of Repairs}} \tag{6}$$

4. Validation

4.1 Validation Scenario

The validation scenario took place in a case study involving a bakery SME located in Peru, which specialized in producing various pastries and desserts, including cakes and soufflés. This company faced significant operational challenges related to production delays, equipment downtime, and inconsistent product quality, all of which negatively impacted customer satisfaction. The case study focused on improving the efficiency and reliability of production processes to ensure timely order fulfillment. The company operated with approximately 40 employees distributed across different areas, including production, administration, and sales. Its primary products were cakes, with chocolate cake representing 71% of total sales revenue. The production process was largely manual, and there were no standardized procedures in place, leading to inefficiencies in machine operation and workflow management. The company's clientele consisted of both direct customers and corporate clients, the latter often requiring customized orders for special events. The case study aimed to address these operational issues by implementing Lean Manufacturing tools such as 5S, Autonomous Maintenance, and Process Standardization.

4.2 Initial Diagnosis

In Figure 2, the problem tree illustrates the diagnostic summary performed in the case study to identify the reasons and root causes contributing to the research problem. The primary issue identified was a high rate of failure to deliver products on time, with the case study showing a failure rate of 22.19%, compared to the industry standard of 8.77%. This significant gap resulted in an economic impact of 576,000 PEN per year, representing 21.9% of the company's annual revenue. The causes leading to this issue were divided into two main categories: high unproductive times (49%) and a high rate of defective products (33%). Root causes of these unproductive times included long search times for production tools (21.6%), constant machine failure (63.2%), equipment without calibration (46.8%), and poor working methods (29.7%). The purpose of this diagnostic analysis was to systematically identify and address inefficiencies within the production process that were directly affecting the company's ability to meet delivery deadlines, providing a clear framework for targeted interventions aimed at improving productivity and operational efficiency.

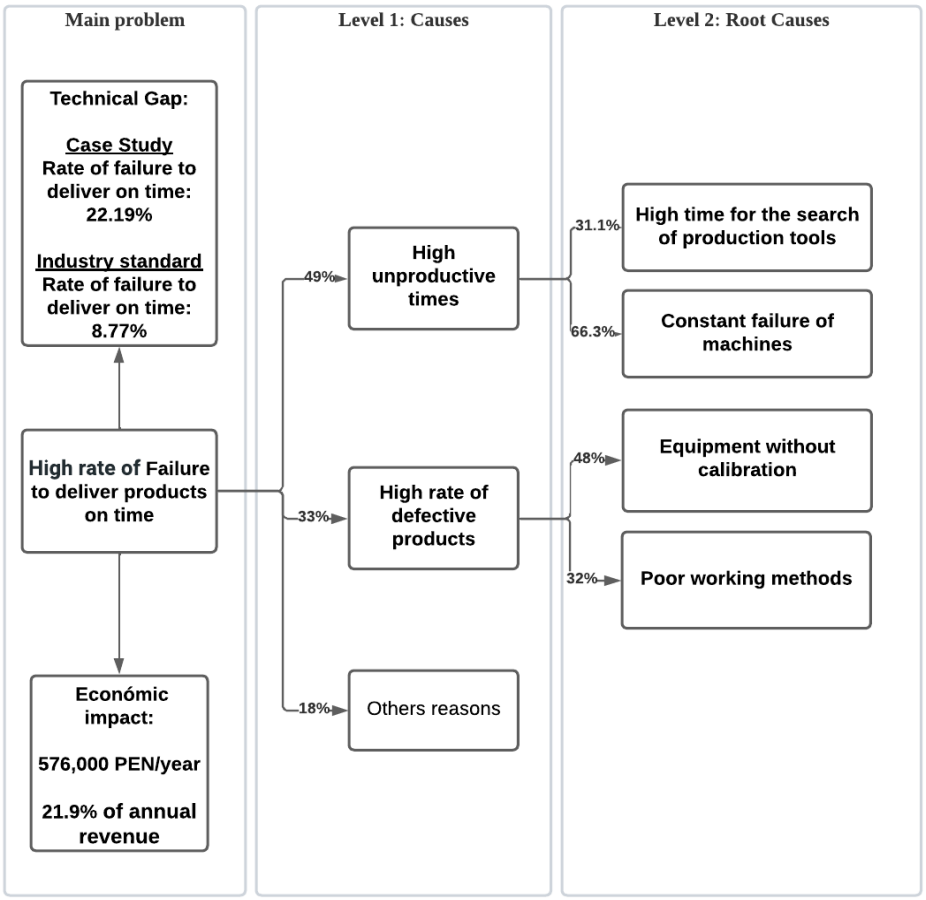

Figure 2. Problem Tree

4.3 Implementation of the model in the case study

The implementation of Lean Manufacturing techniques in small and medium-sized enterprises (SMEs) often focuses on improving operational efficiency and reducing waste. In this case study, a bakery SME faced significant challenges related to inefficiencies in production, equipment downtime, and inconsistent product quality, which negatively impacted its ability to meet delivery deadlines. The introduction of Lean tools such as the 5S methodology, Autonomous Maintenance, and Standardization aimed to address these issues by streamlining processes, improving machine reliability, and ensuring consistency in product quality. This section outlines the detailed application of these Lean tools, providing quantitative data to highlight their impact on the bakery's operational performance.

Implementation of 5S in the Case Study

The implementation of Lean Manufacturing techniques in this bakery SME was centered around the 5S methodology. The process began with the formation of a 5S committee, responsible for coordinating the activities across departments and ensuring that all employees received adequate training. The committee's first task was to establish a preliminary audit to assess the current state of the workplace. The audit used standardized forms to evaluate key 5S factors such as organization, cleanliness, and the ability to maintain these improvements.

The initial audit results indicated that Seiri (organization) was implemented successfully, with a score of 4 out of 5. However, Seiton (orderliness) and Seiketsu (standardization) were partially satisfactory, scoring 2 and 3 respectively, while Seiso (cleanliness) and Shitsuke (discipline) received scores of 2 and 0. This audit highlighted the need for substantial improvement in maintaining cleanliness and discipline in the work area.The next phase of Seiri involved removing unnecessary items that cluttered the workspace. The team applied a red tag system, marking over 100 items for disposal, with 23 of these being molds, 12 hand mixers, and 36 containers deemed unusable due to rust. The estimated space freed up by removing these items was 35 square meters, which allowed for a more streamlined

production flow. After the implementation, the number of unnecessary items decreased by 85%, demonstrating a significant reduction in workplace clutter.

Following the Seiri phase, the Seiton phase focused on organizing essential tools and equipment into designated locations to minimize search times. The average search time for tools before implementation was 25 minutes per hour, as operators frequently misplaced key items. After applying Seiton, the average search time decreased to 8 minutes per hour, representing a 68% reduction in time wasted. This directly contributed to an increase in productivity, as more time could now be allocated to actual production tasks.In the Seiso phase, cleanliness protocols were introduced, requiring workers to clean equipment at the end of each shift. Initial audits showed that equipment cleanliness was far below standard, particularly in the baking and mixing areas where flour buildup was prevalent. After the introduction of cleaning schedules and visual control mechanisms, the cleanliness score increased from 2 to 8 out of 10. This improvement not only enhanced the work environment but also reduced the likelihood of machinery malfunctions due to improper maintenance.

The final audit, conducted three months after the 5S implementation, showed a marked improvement. The total score increased from 11 to 36 out of a possible 50 points, indicating a 70% overall enhancement in workplace organization and cleanliness. Additionally, the time spent searching for tools decreased from an average of 77 minutes per shift to 29 minutes, a 62% reduction that directly contributed to a 30% improvement in order fulfillment rates. The figure titled "Results 5S Audit" is a radar chart comparing the results of a 5S audit before and after implementation, with the objective target also shown. The radar chart displays five axes, each representing one of the 5S elements: 1S (Seiri), 2S (Seiton), 3S (Seiso), 4S (Seiketsu), and 5S (Shitsuke). The blue line represents the initial audit results, where scores were significantly low across all elements. The orange line indicates the improved scores after implementing 5S practices. The gray line represents the objective score for each category, which has yet to be fully achieved but demonstrates significant progress post-implementation.

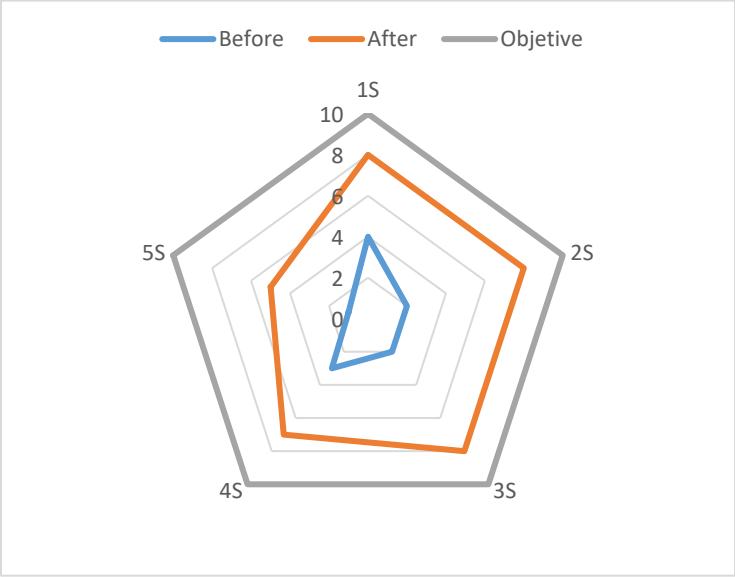

Figure 3. Results 5S Audit

4.4 Autonomous Maintenance Implementation

Autonomous maintenance was introduced to address the high levels of equipment downtime and operator errors that plagued the bakery. Prior to implementation, the bakery experienced an average of 101.15 minutes of machine downtime per week, resulting in the loss of 17 products per month. This downtime equated to an estimated monthly revenue loss of 1,190 soles. The most significant issues involved the ovens, which frequently overheated or shut down unexpectedly, and the mixing machines, which suffered from blockages and obstructions.

To mitigate these problems, a maintenance schedule was established, and operators were trained to perform basic maintenance tasks such as lubrication and cleaning. Training sessions were conducted weekly over a period of three months, and by the end of this period, 100% of the operators had passed the maintenance competency tests.

The immediate impact of this intervention was a decrease in machine downtime. By December, machine downtime had decreased by 37 hours, reducing monthly product losses from 17 to 5. Additionally, the bakery saved approximately 3,430 soles in lost product value, contributing to a significant improvement in the company's bottom line. The MTTR (mean time to repair) improved from 5.10 hours in September to 3.33 hours by December, a 35% reduction. The MTBF (mean time between failures) increased from 24.33 hours to 61.33 hours, representing a 150% improvement in equipment reliability.The bakery also saw a reduction in rework and defects. Before maintenance training, the number of defective products, particularly cakes that were overbaked or underbaked due to oven temperature fluctuations, averaged 30 units per month. This number dropped to 12 units per month after the operators were trained to monitor and maintain the ovens more effectively. These improvements reduced the rework rate by 60%, saving an additional 2,100 soles per month.

4.5 Implementation of work standardization

Standardization was introduced in tandem with the maintenance strategy to ensure that operators followed consistent procedures. Prior to this, operators used informal, personal methods for tasks like mixing and baking, resulting in inconsistent product quality. To address this, standardized work instructions were developed for all major processes, including ingredient preparation, mixing, and baking. The introduction of these instructions aimed to reduce variability in production times and improve product consistency.The first three months of process standardization showed a marked improvement in product quality. The percentage of defective cakes due to improper procedures dropped from 9.52% to 3.85%, a reduction of over 60%. This improvement in quality control helped the bakery to recover 91.23% of its potential revenue, as fewer products were rejected or sent for rework.

In addition, standardization reduced the cycle time for cake production. Before the changes, the average cycle time for producing a batch of cakes was 85 minutes. After implementing standardized procedures, this was reduced to 70 minutes, a 17.6% reduction in production time. This increase in efficiency allowed the bakery to fulfill more orders within the same production window, contributing to a 25% improvement in customer satisfaction due to on-time deliveries.Figure 4 shows the levels of effort devoted to training sessions. The x-axis represents the different levels of effort: Low, Sufficient, Satisfactory, High, and Excellent. The y-axis shows the number of participants corresponding to each effort level. The chart reveals that most participants (7) rated their effort level as "Satisfactory," while 4 participants considered their effort "High," and 3 rated it "Sufficient." There were no ratings for "Low" or "Excellent" effort.

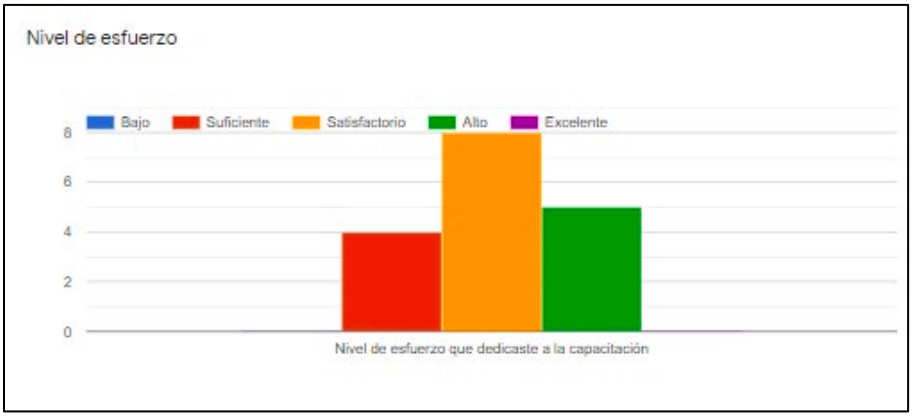

Figure 4. Results of the Autonomous Maintenance Training

5. Results

In Table 1, the results of validating the production model based on Lean Manufacturing and TPM for SMEs in the bakery sector are presented. The rate of order fulfillment improved significantly, rising from 77.81% to 91.23%, reflecting a 17.25% increase. The 5S audit score showed remarkable progress, increasing from 17% to 90%,

representing an impressive 441.35% improvement. The time spent searching for materials decreased drastically, from 77 minutes to 29 minutes, indicating a reduction of 62.34%. The reprocessing rate of products was reduced from 23% to 13%, showing a 43.48% improvement. Furthermore, the Mean Time Between Failures (MTBF) increased by 152.08%, while the Mean Time to Repair (MTTR) decreased by 22.01%. These results demonstrate the effectiveness of the implemented model in optimizing production processes and enhancing operational efficiency.

Table 1. Results of the validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Rate of fulfilment of orders	%	77.81%	95.00%	91.23%	17.25%
5S Audit	%	17%	100%	90%	441.35%
Time spent searching for materials	minute	77	25	29	-62.34%
Rate of reprocessed products	%	23%	10%	13%	-43.48%
MTBF	hours	24.33	65	61.33	152.08%
MTTR	hours	4.27	3.5	3.33	-22.01%

6. Conclusions.

The main findings of this study indicate significant improvements in operational efficiency, product quality, and equipment reliability within the bakery SME sector through the application of Lean Manufacturing and Total Productive Maintenance (TPM) tools. The 5S methodology improved workplace organization by 70%, reducing clutter and unnecessary search times, while the implementation of work standardization lowered defective products by 60%. Autonomous maintenance, which empowered workers to perform routine machine care, led to a 35% reduction in mean time to repair (MTTR) and a 150% increase in mean time between failures (MTBF). These results validate the efficacy of Lean and TPM methodologies in optimizing bakery operations and minimizing inefficiencies.

The importance of this research lies in its ability to address critical issues in the bakery SME sector, particularly in Peru, where operational inefficiencies hinder growth and competitiveness. By improving production processes, this study not only enhances product quality and customer satisfaction but also ensures sustainable business practices. The adoption of Lean and TPM tools is critical for these enterprises to maintain competitiveness in an increasingly demanding market, making this research essential for broader application within the sector.

In terms of contributions to the field, this research provides empirical evidence on the successful implementation of Lean and TPM in small-scale food production environments, an area that has been underexplored in the literature. The study contributes to the body of knowledge by offering a replicable model for improving operational efficiency in bakery SMEs, which can be adapted to other sectors within food production. This model bridges the gap between theoretical frameworks and practical applications of Lean Manufacturing and TPM in real-world SME settings, making it a valuable resource for both scholars and practitioners in industrial engineering.

Final observations suggest that while the implementation of Lean and TPM has yielded positive outcomes, continuous improvement is crucial for sustaining these gains. Employee engagement and regular audits should be maintained to ensure the long-term success of these methodologies. Additionally, future studies could explore the integration of advanced technologies, such as automation and real-time data analytics, to further enhance productivity and reduce human error in bakery operations. This research highlights the need for ongoing development and innovation in process optimization strategies for SMEs.

In conclusion, this study offers a solid foundation for future research on the application of Lean and TPM tools in SMEs, particularly in the food production industry. It calls for more in-depth studies on the integration of new technologies and methodologies to build upon the progress achieved in this research. This investigation serves as a call to action for industry professionals and scholars to explore new approaches that could further improve operational efficiency, product quality, and overall competitiveness in the SME sector..

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