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Original Article

Lean-TPM Production Model for Efficiency and Quality Enhancement in the Brewing Industry: Insights from a Peruvian Case Study

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Abstract *- The brewing industry in Peru faces significant challenges related to production inefficiencies, including extended setup times, downtime, and defective product rates. Prior research has demonstrated the potential of Lean Manufacturing and Total Productive Maintenance (TPM) methodologies to enhance operational performance, yet their specific application in brewing remains underexplored. This study proposed a Lean-TPM model integrating tools such as SMED, 5S, Andon, and Autonomous Maintenance, systematically applied using the PDCA cycle. The model was implemented in a Peruvian beer production SME, achieving a 29% reduction in setup time, a 72% decrease in downtime, and a 56% improvement in product quality by reducing defects. These outcomes highlight the adaptability and effectiveness of Lean-TPM tools in resource-constrained settings. This study offers literature coverage and an implementation framework model for Small and Medium Enterprises (SMEs) that enables them to maintain competitiveness and sustainability. Further research should focus on how to better exploit more modern technologies.*

Keywords *- Lean manufacturing, Total Productive Maintenance, Brewing industry, Operational efficiency, Quality improvement.*

1. Introduction

The brewing industry is vital across the world for economic, cultural and social interaction development. The industry has experienced great development over the past years, especially in Latin America, which has seen a spike in demand for different beer products. In Peru, the said country has had tremendous unemployment benefits from the industry, growing local businesses significantly. The Peruvian Association of Beer Producers has been keeping track and they reveal that there has been a significant increase in consumption of beer. The consumption leap can be attributed to increases in the popularity of craft beers as customers taste evolve. This increase not only shows the importance of the brewing industry in revenue generation but also how it affects the cultural identity of Peruvians who use it as a central piece in all social events and celebrations.

Although the brewing sector pulls considerable weight economically, it has a number of production problems that affect its overall efficiency. The primary one is the low efficiency of production processes, worsened by rework as a result of inadequate sealing and filling. To elaborate, unfilled cans have to be filled before they are sealed, or else they are not cost-effective to use. Thus, filling and sealing cans at the appropriate level wastes resources [1]. Other variables, such as breakdowns of machines that lead to production stopping or machinery that takes longer to set up, also serve to further complicate the situation. These factors affect profits while posing a threat to the quality of the end product, which in turn can lead to client dissatisfaction and competition in the market. The combined effect of these challenges requires proper attention and measures that will improve production efficiency in the brewing industry.

Tackling these production problems is vital for achieving improved operational performance and preserving the competitiveness of the brewing industry. The application of methodologies such as Lean Manufacturing, as well as Total Productive Maintenance (TPM) has been shown to be successful in various disciplines, including the brewing sector. The focus on waste reduction, continuous improvement and proactive maintenance can dramatically reduce downtime while raising the level of product quality [2]. In light of this, the use of Andon for visual management and the Single-Minute Exchange of Die (SMED) technique for set-up reduction are Lean tools that are likely to aid in addressing these operational issues in the fast-changing production paradigms [3]. These methodologies will enable the brewing companies to not only optimize their processes but also foster a culture of improvement that is needed for growth.

There is scant literature on the tailoring of Lean Manufacturing and TPM tools to the brewing industry, although their respective advantages are well-known. While much effort has been directed toward their implementation in other areas of manufacturing, little is known about the issues specific to breweries. This study's unique contribution is the design of a production model that applies Lean tools such as 5S, Andon, and SMED along with autonomous maintenance, a TPM practice.

This paper focuses on the Peruvian brewing industry and aims to demonstrate how these methodologies may be modified to solve specific production difficulties encountered by breweries. The expected results from the study will enhance the literature as well as provide relevant solutions to practitioners who want to increase operational performance within the industry [4].

To summarize, the Peruvian brewery industry is currently experiencing severe issues with production that need to be properly addressed. The combination of Lean Manufacturing and Lean TPM techniques presents itself as a possible solution for enhancing the productivity and sustainability of the brewing business. This research aims to add to the current literature and give practical recommendations to breweries to help them improve their operations and compete in a tougher business environment [5].

The output of this study will undergo comparative scrutiny in reference to the existing literature to determine more effective methods towards the proposed model and further augment the knowledge of Lean and TPM techniques in the brewing industry.

2. Literature Review

2.1. Lean Manufacturing in Beer Production

The implementation of continuous improvement methodologies in the brewing industry has been the subject of study in various research works, highlighting the application of Lean Manufacturing. This methodology focuses on waste elimination and process optimization, resulting in significant improvements in operational efficiency.

For instance, Apaza [6] discusses how the implementation of Lean Manufacturing in a metalworking company improved the Overall Equipment Efficiency (OEE), which is applicable to the brewing industry where production efficiency is crucial. Additionally, Landazábal et al. [7] emphasize that Lean philosophy aims to optimize the production system by eliminating tasks that do not add value. This principle can be directly transferred to beer production. In the context of brewing, Vázquez-Alfaro et al. [8] analyze the value chain of the brewing industry in Mexico, suggesting that the implementation of Lean practices can enhance each link in this chain, from primary production to final consumption.

Furthermore, Benítez and Silva [9] present a case where the application of Lean Manufacturing in a small foundry resulted in significant productivity improvements, suggesting that similar outcomes could be expected in beer production.

2.2. SMED Methodology in Brewing

There have been studies done on the Single-Minute Exchange of Die (SMED) Methodology in relation to the brewing sector pertaining to the minimization of changeover time within the production system. This is a very useful technique in breweries to enhance agility and effectiveness. Prior examinations have indicated that the effective implementation of the SMED can greatly minimize downtime, so that firms can respond to these demands in a timely manner.

For instance, with regard to beer brewing, incorporating SMED could ease the shifts from one beer style to another while maximizing the use of available resources and minimizing the time wasted. Also, research conducted in other industries has suggested that much more can be gained with customer-focused changeover strategies because there is a shift from traditional mass production to more dynamic and diverse production [7]. SMED's applications in the brewing industry are specifically valid because there is fierce competition in the market, and greater public attention is being shifted toward a better variety of products offered [10].

2.3. 5S Methodology in Brewing

The 5S methodology has been applied in several industries, including in the brewing industry, because of its utility in enhancing productivity through workplace organization and standardization. This methodology is useful in ensuring safety and improving the quality of the products as well. In brewing, use of 5S practices will ensure that there is a clean and tidy workplace which is critical to preventing contamination and ensuring that the desired quality is achieved [6].

According to Landazábal et al. [7], the use of 5S in a metal working company greatly improved the product quality, and it could be assumed that the results would also be applicable in brewing production. Equally important, use of 5S in a company enhances organizational culture and promotes employee creativity that increases the commitment and the overall engagement of the company’s strategy [8].

2.4. Autonomous Maintenance in Brewing

Autonomous maintenance is yet another methodology that has started to gain traction in the field of brewing because it empowers operators to take care of their machines themselves. This practice not only improves equipment availability but also is conducive to a sense of responsibility and initiative among the workers. Regarding beer production, autonomous maintenance is very important in averting equipment breakdowns which might halt production or impair the quality of the beer. Other studies contend that autonomous maintenance has been adopted across various industries with pleasing results where maintenance costs have gone down drastically while operational performance has increased [7]. Also, training operators on maintenance techniques have been linked to more informed processes due to better anticipatory identification of problems that, if left unattended, can lead to critical failure [9]. Given this evidence, the world of brewing may stand to benefit from the adoption of autonomous maintenance as one of the thrusts towards efficiency and performance cost reduction.

2.5. ANDON Methodology in Brewing

At the end of the day when, ANDON a methodology for real-time visualization of processes and problem communication is very important in the effective management of the beer production processes. It enables the operators to quickly identify and rectify the problems resulting in reduction of downtimes and increasing the responsiveness of the systems. In brewing, its use is especially beneficial because it allows a stringent balance of product quality to be maintained throughout various stages of production [7]. Such systems have been proven to be more operationally efficient while also decreasing the waste produced in different industries [10]. Not only has that but real-time production visualization also helped in improving the organization's culture into one that values performance and collaboration. Therefore, the addition of these capabilities in brewing plants may increase the process parameters improvement and product quality.

3. Contribution

3.1. Proposed Model

A production model is described in Figure 1 with respect to the improvement of the efficacy of the beer production sector, which is based on Lean Manufacturing principles and Total Productive Maintenance (TPM). This model employed flexible tools like SMED, 5S, and Andon plus autonomous maintenance with a view to optimizing time, reducing waste, and advancing operational sustainability. SMED approach made it possible to study and convert internally performed activities into external ones, enabling shift changes greatly improving setup times and ensuring greater equipment availability.

The 5S workplace organization system created an orderly and clean working place, which helped in instilling discipline among operators. With regards to the TPM system, the practice of autonomous maintenance enabled the personnel to conduct basic inspections and adjustments, thus improving equipment operational reliability and reducing downtime. In parallel, the Andon system enhanced response capacity through the use of alarming devices associated with the monitoring system of the production lines, pinpointing relevant deviations and enabling corrective actions to be taken promptly. This integrative model not only solved particular quality and efficiency problems but laid the groundwork for ongoing improvement and sustainability in production processes.

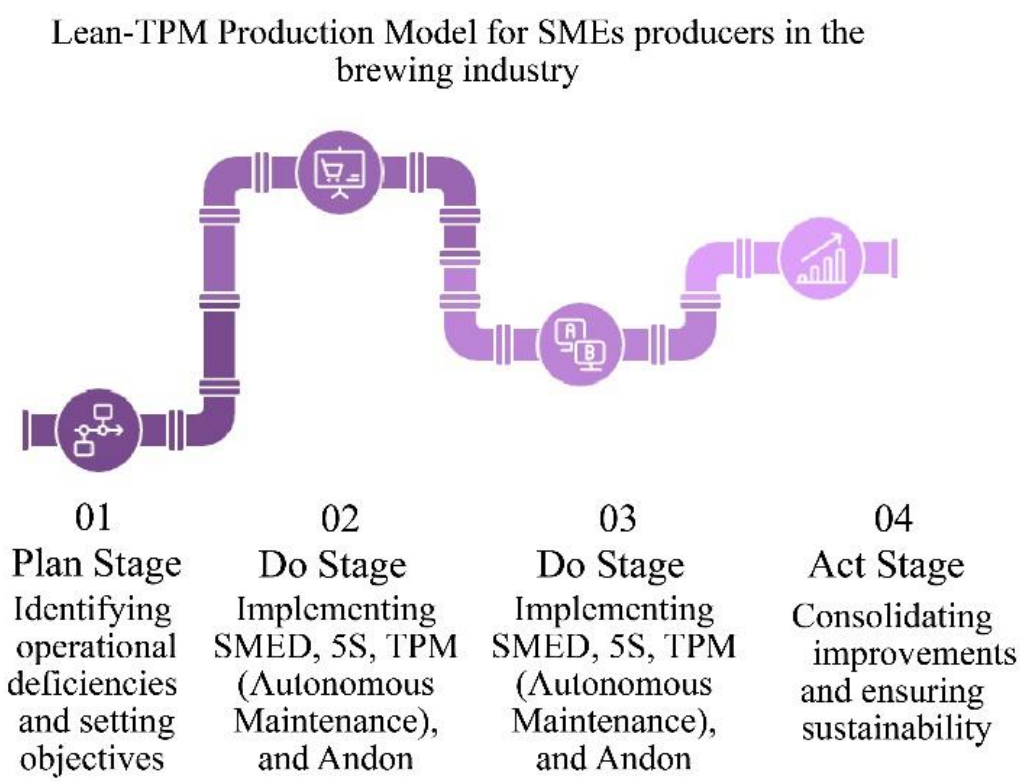

Fig. 1 Proposed model

3.2. Model Components

The model developed with these particular improvements with respect to beer production represented in the attached figure has to be regarded as a major contribution to the field of industrial engineering, both from the technical and practical aspects. It combines the principles of Lean Manufacturing and Total Productive Maintenance (TPM) in some of the key elements that have been incorporated into the Plan, Do, Check, Act (PDCA) framework.

The design is very much focused on addressing the important aspects of the production process, such as addressing the issues around waste and unproductive times, as well as improving efficiencies and processes in a productive manner and maintaining those improvements for a long time. At the same time, it looks at tackling the more critical areas of the production process where defects emerge and lower the resources used, improve maintainability, and increase the reliability of the equipment. This method aims to alleviate existing processes, making them stronger and easier to adapt to shock elements while meeting the requirements of the industrial competition.

3.2.1. Stage 1: Plan

In this first stage of the PDCA cycle, the preparatory activities involved research which helped comprehend the nature of operational shortcomings, as well as formulate specific goals toward their improvement. At this step, an extensive plan of the diagnosis of the production system was drawn, which consisted of studying the historical data, observing the work procedures, and conducting interviews with relevant personnel. This analysis revealed alarming issues such as chronic technical breakdowns, failure to adhere to the filling level of the cans, and high setting up times for the equipment. Further, the effect of these shortcomings on productivity and competitiveness indicators were also measured.

From this analysis, specific objectives ranging from waste minimization to improving plant performance were set at the study level and later on complied with on the facility model. As a result, necessary resources were also ranked, and elaborate timetables were drawn up to ensure model compliance. This proactively formulated plan served as a basis neutral intervention aligned with continuous improvement.

3.2.2. Stage 2: Do

SMED Implementation

Setups of the production lines were Single Minute Exchange of Die (SMED)-optimized to quicken the setup times. A comprehensive examination of the operations which are performed during the changes in format was undertaken which made it possible to distinguish between internal and external activities. Internal works, which were feasible only when the equipment was halted, were converted to external works, which were executed prior to or post the machine halt. In addition, supporting apparatuses were also introduced to ease the process of evolution and speed up the changes. This not only reduced idle time but also increased the productivity of operations as a whole.

Application of 5S

The 5S program was designed to foster the maintenance of an organized and efficient workspace. The activities commenced with the sorting step, wherein materials and tools were sorted, and anything not required was discarded. Then, workstations were arranged in such a way that essential materials could be retrieved in no time. Systematic cleaning was formally instituted as a hprioitised ongoing activity. This level of organization meant that cleaning and care were simply routines to be performed and supported active engagement in waste management. Standardization meant these practices were uniformly applied to every production line, whereas discipline facilitated the employee's adherence to the improvements made. This contributed positively to waste reduction and safety in the workplace.

Autonomous Maintenance

Autonomous maintenance was introduced as a practice with undue freedom for the operators under the scope of TPM. Employees were trained in common maintenance tasks that included but were not limited to cleaning, inspection, and machine adjustments. The action taken was aimed at improving machine availability and reliability through the detection of operational anomalies. Also, checklists were introduced as a standard to record appropriately performed activities. Staff participation not only helped to lessen the burden of the specialized maintenance team but also created a communal attitude towards constructive assets.

Introduction of Andon

The Andon tool was introduced to enhance the visual optimization of processes undertaken in production. Weight sensors were placed on filling lines, enabling the real-time measurement of the weight of cans. Whenever the established range is crossed, the system produces both visual and auditory alerts, which enable immediate intervention. The solution adopted not only limited defective product manufacturing but also made recurring problem identification easier. Further, the Andon system enhanced the communication between operators and supervisors and ensured incidents were dealt with rapidly and in a coordinated manner.

3.2.3. Stage 3: Check

The evaluation phase focused on assessing the outcomes of the actions that were undertaken. Prior to the use of the tools, performance indicators served as comparisons to the results achieved. These included less time spent in set up, reduced number of defective items, and better availability of the equipment. Surveys and interviews captured perceptions of the implemented changes and the degree of commitment to the new practices. The feedback was crucial in determining the features of the model that need improvement as well as the ones that need consolidation. Furthermore, each of these actions was evaluated during the demonstrations for a set period so that the procedures could be updated accordingly.

3.2.4. Stage 4: Act

The last stage of the model centered on the achieved improvements and creating an infrastructure for perpetual improvement. Operational procedure manuals were compiled to normalize applied actions so that they are reproducible and sustainable in the long run. These manuals contained maintenance tasks, setup activities and Andon tool criteria and monitoring procedures. In addition, teams of different disciplines were formed for the purpose of system performance supervision and new improvement projects. This approach made it possible to increase the chances of the implemented practices being relevant and the organization continuing to progress toward greater efficiency and competitiveness. In general, the proposed model marked a major development in the management of productive processes towards world-class standards and global market responsiveness.

3.3. Model Indicators

To evaluate lean and TPM approaches to production in a brewery, specialized metrics were developed. These metrics were used to track and evaluate progress during the case study which served as supporting evidence to determine important elements that affect the brewing process. This approach enabled a deeper analysis of performance metrics. This holistic approach enhanced control and monitoring of the parameters in the industry, enabling its continuous growth and improvement.

3.3.1. Setup Time

Setup time corresponds to the total time needed to get mechanics ready for production activities, generated by summing the time taken in each of the constituent activities. This metric is very important in understanding setup inefficiencies that exist in every organization so that productivity and machine utilization can be improved.

$$\text{Setup Time (minutes)} = \sum_{i=1}^{n} \text{Activity Duration}_i$$

3.3.2. Downtime

Downtime measures the total time equipment is inactive due to unplanned events such as maintenance, setup, adjustments, or failures.

$$\text{Downtime (minutes)} = \text{Unplanned Maintenance Time} + \text{Setup Time} + \text{Adjustment Time} + \text{Failure Time}$$

3.3.3. Rate of Defective Products

This indicator calculates the proportion of defective units produced compared to the total output. It reflects the quality of the manufacturing process, with a lower rate indicating improved production standards and reduced waste.

$$\text{Rate of Defective Products (\textbackslash\%)} = \left(\frac{\text{Defective Units}}{\text{Total Units Produced}}\right) \times 100$$

4. Validation

4.1. Validation Scenario

The validation scenario was carried out in a case study within the Peruvian beer industry. This company specializes in the production of canned beer, focusing on two main product presentations, 355 ml and 473 ml. In 2022, the organization faced a significant challenge related to low efficiency in its production processes, with an efficiency rate of 78.10%, falling short of the competitive standard of 85%. Despite its established presence in the national market, the company has struggled with operational challenges such as production downtime, excessive setup times, and errors during critical stages like filling and sealing.

4.2. Initial Diagnosis

The diagnosis conducted in the case study revealed low efficiency in the beer can production process, reaching 78.10% in 2023, which represents a 6.90% gap compared to the competitive standard of 85% established in the literature. This inefficiency was attributed to three main factors: rework, accounting for 13.95% of the issue, was caused by errors in the sealing process. Errors in operational development, representing 39.20%, were linked to two root causes: cans failing to meet the required filling level, highlighting the need for systems such as Andon, and technical machinery failures, which accounted for 27.01% and could be mitigated through autonomous maintenance based on 5S principles within a TPM framework.

Lastly, process stoppages due to machinery were the most significant factor, with an impact of 46.85%, stemming from extended equipment setup times, which represented 19.84%, suggesting the implementation of the SMED methodology to reduce these delays. This scenario led to an economic impact of 15.34%, resulting in losses of US$ 554,798.83 due to unmet demand, underscoring the urgency to optimize the production process.

4.3. Validation Design

The proposed production model, which integrates the Lean and TPM tools, was validated by the pilot validation method. In the case study, the usage of this method took 4 months and included all the proposed techniques. These include 5S, SMED, ANDON and Autonomous Maintenance. Each of these tools is discussed in detail below.

With the above Lean-TPM production model, the case study focused on the shortcomings during the beer production stage by employing techniques like SMED, 5S, TPM, Andon, and others. These tools were incorporated into the steps of the PDCA cycle, aiming at improving operational efficiency, reducing waste, and enhancing equipment's and systems' reliability at all levels. This model sought to improve the production system to respond to the market needs without compromising on quality by focusing on measurable and changeable outcomes.

4.3.1 SMED Implementation

SMED was instrumental in improving the setup process when there were changes to be made in the canning line, which served to minimize inefficiencies. It involved a thorough inspection of every single one of the setup activities and separating them into internal and external tasks. Understandable tasks were performed only during the idle periods of the equipment; thus, restructuring them served to reduce internal downtime. When machinery was on the run, these external tasks were restructured and standardized to internal tasks. This change employed the incorporation of these specialized tools for adjustive modifications as well as reconfiguration of the workstations for better access.

Workshops in practice were carried out together with operators to identify the sore areas in the setup methodology like excessive movement or notions and misplaced tools. A participative culture was created out of these workshops, where operators came forth with plans to enhance the workflows.

The result is a 27% drop in the setup times in addition to other productivity metrics illustrating the potential of SMED. The implementation positively increased the efficiency of machine usage and labor resources effective use, enabling the production timetable to be followed more accurately.

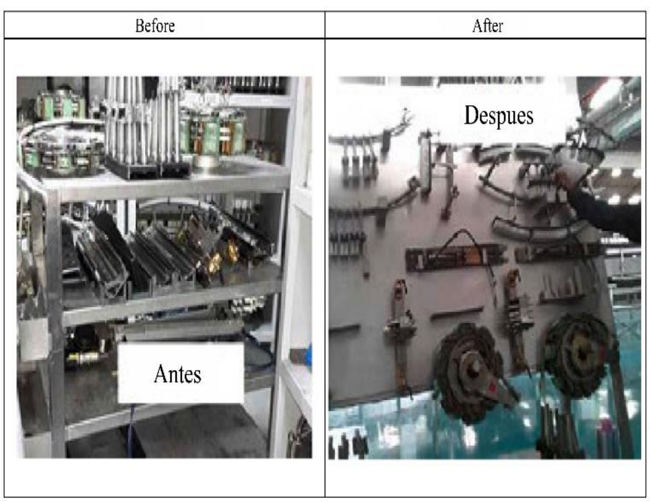

Fig. 2 Format and setup change

In Figure 2 the change in the preparation phase when the format changes is shown. The “Before” image depicts misplaced tools, while the “After” image displays the orderly setup of the tools on the wall. These efforts improved efficiency by minimizing the time required for retrieval and increasing the organization of the workspace, which is in line with Lean Manufacturing concepts.

4.3.2. Autonomous Maintenance

Operators were enabled to carry out basic maintenance on the machines through training seminars for washing, lubrication, cleaning, and adjusting dysfunctional components. These were intended to familiarize operators with daily maintenance and abnormalities handling techniques. Maintainers were also equipped with enhanced visual management skills, including color-coded checklists and schedules. The above routinely designed alterations made maintenance activities more routine than irregular.

A predefined system for reporting anomalies was formulated to enable operators to document breakdowns that were ordinarily unreported. Such redundant reports were screened by maintenance supervisors at regular intervals in order to enhance the communication gap that exists between operational personnel and the technical team. By the end of this period, the downtimes resulting from equipment breakages had reduced by 39% due to enhanced equipment availability and reliability thanks to employing autonomous maintenance techniques.

4.3.3. 5S Methodology

This step involved accomplishing the 5S to ensure a clean, organized and tidy workplace, which was the pre-requisite for high-quality products to be produced consistently. The first step is the Sort stage. In this step, unnecessary materials and tools are removed from the workstations. This is followed by Set in Order which facilitates the basic organization of items needed to enhance speed in retrieval and use. Order was implemented through custom tool racks and labeled storage bins.

In cleanliness, contamination is the major setback and Seiso stands for Shine routine as well cleaning schedules ensure organizational hygiene. Critical as a result of being in food and beverage production environments is Seiketsu standardize which cleaning and organizational procedures are applied to all production lines as a uniform practice.

Finally, audits and employee training programs maintained discipline under the new order through sustainable practices. The principles once ingrained in daily practice reinforced aesthetic changes in the organization, lowered search times, and reduced errors made. With proper principles in place, the organization achieved a safe and productive work environment while adhering to the Lean concept of eliminating waste.

GESTIÓN DE MANTENIMIENTO AUNTÓNOMO DEL EQUIPO LLENADORA / ENVASADORA DE CERVEZA TRES CRUCES

Área:	Equipo:	Significado de Símbolos:	Significado de Formas y Colores:		
Envasado de Latas	LLENADORA / ENVASADORA	Inspección, Lubricación, Limpieza, Intervención	○ Producción	Turno (amarillo)	Mensual (morado)
Línea de Producción:	Responsable:		⬡ Mantenimiento	Diario (rojo)	
Lata 355 ml.	Operario		△ Especializado	Semanal (verde)	
				Quincenal (naranja)	

ITEM	COMPONENTE	APOYO VISUAL	CLASE DE ACCION	PROCESO	RECURSOS/UTENSILIOS	EQUIPOS DE PROTECCIÓN PERSONAL (EPPs)	FRECUENCIA
I1	ESTRUCTURA GENERAL			1. Asear acristalados, pisos, conductos, rejilla y almacén posterior.	- Aseador	-Botas Antideslizantes - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR TURNO
I2	VISTA GENERAL DE ESTRELLAS			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar Pulsador, para giro de equipo 4. Inspección y limpieza de sensores y estrellas	- Aseador	-Botas Antideslizantes - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR TURNO
I3	ESTRELLAS Y GUÍAS DE LLENADO			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar interruptor, para giro de equipo 4. Supervisión y aseo de estrellas y guías	- Aseador	-Botas Antideslizantes - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR TURNO
I4	VÁLVULAS ENCARGADAS DEL LLENADO			1. Supervisar válvulas de llenado (nivel)	•	-Botas Antideslizantes - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR TURNO
I5	ELEMENTOS DE MANTENIMIENTO			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar interruptor, para giro de equipo 4. Supervisión y aseo de estrellas y guías	- Aseador - Aceite Neumática - Desengrasante	-Botas Antideslizantes - Guantes Desengrasante Anticorte - Lentes de Seguridad - Casco Anti Golpes	POR SEMANA
I6	CHUCKS DE FIJACIÓN			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar interruptor, para giro de equipo 4. Desacoplar, asear y comprobar si los chucks están desgastados o dañado 5. Purificar los chucks y acoplarlos	- Aseador - Ácido Paracético - Detergente Alcalino	-Botas Antideslizantes - Mandil - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR QUINCENA
I7	RODAMIENTOS Y SISTEMAS DE TRANSMISIÓN			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar interruptor, para giro de equipo 4. Asear con desengrasante 5. Emplear grasa con bomba manual 6. Asear el excedente con desengrasante	- Aseador - Grasa Kluber - Desengrasante	-Botas Antideslizantes - Mandil - Guantes Estéril - Lentes de Seguridad - Casco Anti Golpes	POR MES
I8	PIÑONES			1. Establecer equipo en Modo Manual 2. Introducir Tarjeta 3. Activar interruptor, para giro de equipo 4. Emplear grasa con spray (2 veces) 5. Asear el excedente del spray	- Aseador - Lubricante - Desengrasante	-Botas Antideslizantes - Guantes Estéril Anticorte - Lentes de Seguridad - Casco Anti Golpes	POR MES

Elaborado por:	Validado por:	Autorizado por:
Responsable:	Responsable:	Responsable:
Inicio: Fin:	Inicio: Fin:	Inicio: Fin:

Fig. 3 Autonomous maintenance implementation plan

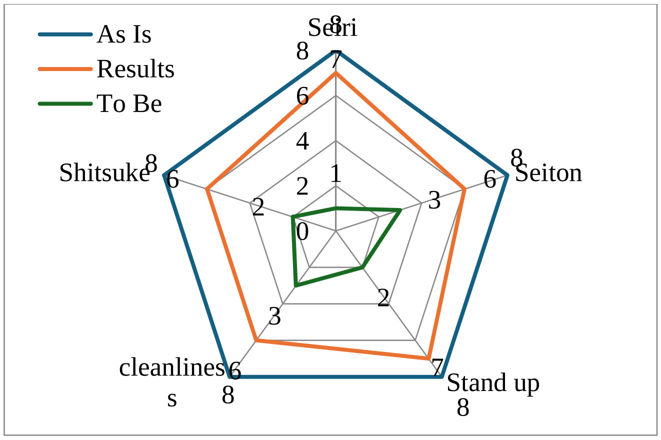

Fig. 4 Initial and final audit 5S

Figure 4 portrays the beginning and end of 5S audit results during As-Is and To-Be stage comparisons. In the radar graph, the impact on the five 5S parameters- Sort, Set in Order, Shine, Standardize and Sustain, is marked. Increased values in the "Results" phase show progress in the implementation of Lean principles in how the workplace was organized.

4.3.4. Andon System Deployment

The Andon system was put in place to facilitate process supervision and enhance response times for deviations using real time information. Weight sensors were placed at strategic locations in the filling line to maintain the required filling levels. These sensors were linked with an Andon system, which provided visual and audible signals by lights and speakers when deviations were detected. Training was provided to operators so that they could respond to these signals adequately and stop the production line if work needed to be done on the issues raised.

Corrective measures could be taken immediately; therefore, the Andon system contributed to the reduction of the reject rate quite significantly. In particular, operators' ability to rectify problems such as inconsistent filling levels that had earlier resulted in defective products turned out to be very effective and did reduce the level of defects. The defect rate was reduced from 2.97 % to 1.3%, which indicates that the system has facilitated improvement in the quality of the output and the reduction of waste.

Additionally, the system facilitated better communication between operators and supervisors, ensuring that problems were escalated and resolved efficiently. Figure 5 illustrates the design of the Andon system, which uses a visual indicator to monitor weight compliance in real time. The system employs a color-coded alert: red signals non-compliance, prompting the process to stop, while green confirms adherence to specifications. This design ensures quality control for 355 ml and 473 ml cans.

Andon (visual indicator)					
The color indicates the weight range to evaluate in each can once filled to verify it is within specifications.			CAN 355 ml		Less than 363g or greater than 365g
					Between 363g and 365g
RED		Weight does not comply, stop the process.	CAN 473 ml		Less than 484g or greater than 486g
GREEN		Weight is within specifications.			Between 484g and 486g

Fig. 5 Andon system

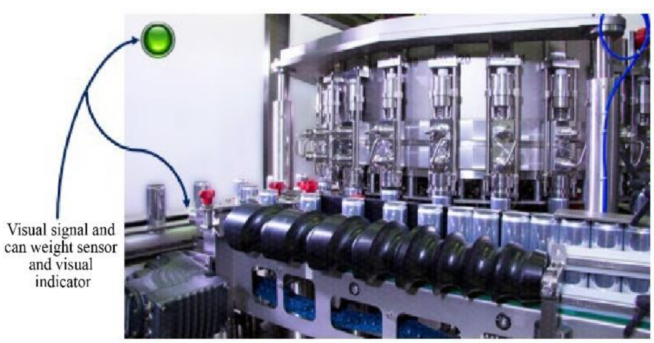

Fig. 6 Andon prototype

Figure 6 depicts the Andon prototype implemented in the production line. It features a weight sensor and a visual indicator integrated into the canning process. The green signal confirms that the weight is within the specified range, while deviations trigger alerts. This system enhances real-time monitoring, ensuring consistent product quality and immediate corrective actions.

4.4. Results

Table 1 shows a significant reduction in key indicators following the implementation of the proposed Lean-TPM model in a beer production company. Setup time experienced a notable improvement, decreasing by 29%, from 41 to 29 minutes, reflecting substantial optimization in process efficiency.

Likewise, downtime decreased by 72%, dropping from 74 to 21 minutes, demonstrating greater operational availability of the equipment. Lastly, the defective product rate showed a remarkable improvement of 56%, reducing from 2.97% to 1.30%, confirming the positive impact of the model on final product quality.

These results validate the effectiveness of the applied tools and reinforce the sustainability of the Lean-TPM approach in optimizing processes within this brewing industry.

Table 1. Results of the pilot

Indicator	Units	As-Is	To-Be	Results	Variation (%)
Setup Time	minute	41	30	29	-29%
Downtime	minute	74	45	21	-72%
Rate of Defective Products	%	2.97%	1.50%	1.30%	-56%

5. Discussion

The study's results align with and expand upon existing literature, demonstrating the effectiveness of Lean Manufacturing and Total Productive Maintenance (TPM) methodologies in addressing operational inefficiencies. Apaza [6] observed notable enhancements in Overall Equipment Effectiveness (OEE) in a metalworking SME, which mirrors the 29% reduction in setup time achieved in this research. Similarly, Landazábal et al. [7] highlighted the impact of 5S and TPM tools on quality and efficiency, results consistent with the 56% reduction in defective product rates observed here. Vázquez-Alfaro et al. [8] emphasized the value of Lean tools in optimizing production workflows in the brewing industry, paralleling the 72% decrease in downtime reported in this study. Finally, Benítez and Silva [9] demonstrated significant productivity gains through Lean integration in small-scale manufacturing, supporting the adaptability and success of the proposed Lean-TPM model in SMEs. These comparisons reinforce the relevance and replicability of the findings within similar contexts.

5.1. Study Limitations

As the focus is on the important improvements in operational efficiency, the limitations of the proposed model also require consideration. The analysis focused on one specific SME that designs footwear, which internally narrows the scope of applicability of the findings to other sectors and/or organizational contexts. There were not addressed external factors like supply chain disruptions and demand changes, which may limit the scalability of the model. Furthermore, because the implementation phase lasted only four months, there was no possibility of evaluating the sustainability of the proposed changes over a long period of time. The lack of a control group also hampers the possibility of separating the influence of the Lean tools alone from other simultaneous organizational activities.

5.2. Practical Implications

This study gives a comprehensive approach for SMEs to apply structured Lean Manufacturing tools to improve productivity and competitiveness. The synergistic combination of 5S, SLP and work standardization provides a logical way of waste minimization, layout efficiency and standardization of important operation processes. The demonstrated improvements in labour productivity, material flow, and time reductions point to the applicability of the model in industries where operations cost, and the inefficiencies of the processes severely impact delivery times. In addition, it emphasizes the self-imposing culture of SMEs that will lead them to promote their employees and lean practices within the institution. In managed settings such as those of emerging economies, the model is simple and very effective in breaking the operational barriers and improving competitiveness in local and international markets.

5.3. Future Works

Future investigations should look into the setting of the proposed model in other industries in order to test its flexibility and applicability. Longitudinal analysis may shed light on the achievability of the improvements attained and their effect on organizational performance over time. The application of these technologies may allow for more accurate layout design and additionally aid in developing forecasting models for process improvement. Also, the amalgamation of Lean tools with Industry 4.0 technologies like the IoT and AI opens a new avenue for instantaneous visualization and decision-making processes. Studies that touch upon the human angle, like the involvement of workers and training, would ameliorate the knowledge of how organizational culture affects the sustained use of Lean. Expanding the model is possible by integrating non-economic measurements, which would tie the model with contemporary needs.

6. Conclusion

The study was able to prove that the incorporation of Lean Manufacturing tools like 5S, SMED, Andon, and even Autonomous Maintenance within a Total Productive Maintenance (TPM) Strategy enhanced the operational capacity of the beer industry SME located in Peru. The introduction of these new processes led to quantitative gains such as a 29 percent reduction in setup time, 72 percent less downtime, and 56 percent less defective products.

These figures attest to the effectiveness of the suggested model in coping with critical relevant gaps IIa, IIb while increasing the reliability of the equipment and the end product quality. Important findings indicate that a structured approach needs to be undertaken towards process improvement in the context of highly competitive production environments with intricate production processes and strict quality guidelines. This study has shown how important the inclusion of Lean-TPM concepts is to make the most of the available resources and processes in SMEs that are limited in resources and capacity. The research addresses individual issues, for example, too much time spent on changing the processes and too many repeated technical problems that always seem to occur in these industries that countries are trying to make more sustainable and competitive. The use of some Andon real-time monitoring enabled tighter control of the processes as well as rapid reactions to any nonconformity-preventing waste. This study demonstrates once again that Lean TPM can be a favourable methodology in SMEs seeking relevance for practical purposes as opposed to striving for theoretical completeness.The research addresses an important issue in industrial engineering by enhancing knowledge of Lean-TPM application in the brewing sector. It also contributes to the literature by its value in construction and modification for enhanced productivity in other industries facing similar situations. Additionally, the research indicates that Lean-TPM can be used effectively to facilitate a culture of constant change, collaboration, and operational achievement.Further research should focus on the functionality of this model on case studies from other industries to test its generalization. From a longitudinal perspective, it would be valuable to assess if the achieved results will be stable and how they influence the company's economics. Furthermore, the implementation of new technologies like IoT sensors or simulation software could improve the efficiency and flexibility of the suggested Lean-TPM model by optimizing real-time monitoring and predictive maintenance strategies.

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