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Integrated Model of TPM, SMED, Poka Yoke, and 5S to Improve OEE in Pole Production in Peru

Milagros Chumbimuni Mayo[1]; Elías Gil Quillas[2]; Carlos Céspedes Blanco[3]
[1,2,3] Universidad Peruana de Ciencias Aplicadas, Peru, *U201914970@upc.edu.pe, U202012732@upc.edu.pe, carlos.cespedes@upc.pe*

Abstract– This study presents a management model to increase productivity in pole manufacturing in Lima, Peru, through the implementation of SMED, 5S, TPM, and Poka Yoke techniques. The research addresses the issue of low utilization of installed capacity in a FRP pole manufacturing company, which did not exceed 70% in 2023 despite sector growth. The importance of this study lies in its potential to significantly improve OEE indices. The proposed model includes detailed steps for implementing SMED, which reduces setup times; 5S, which organizes the workplace; TPM, which ensures operational availability of equipment; and Poka Yoke, which minimizes production errors. The validation of the model in a case study involved measuring key performance indicators, such as OEE, which improved by 40%, reaching an average of 80.56%. The results also demonstrated a 13% reduction in cycle times and a 40% reduction in setup times. The main conclusion is that integrating these techniques can substantially improve efficiency and profitability in the manufacturing sector.

Keywords-- Productivity, Capacity, Efficacy, FRP poles, Production efficiency.

I. INTRODUCTION

The manufacturing industry is a key sector for Peru's economic development, contributing approximately 12.3% to the national Gross Domestic Product (GDP) in August 2024, with a 2.2% growth compared to the previous year [1]. In particular, non-primary manufacturing, which includes plastic production, has shown a continuous decline for several months, with a 7.6% drop in the first six months of 2024. However, low operational efficiency remains a recurring challenge, compromising its ability to compete locally and internationally. In this context, production processes must be optimized to achieve optimal productivity levels.

This article presents a model based on Total Productive Maintenance (TPM), Single-Minute Exchange of Dies (SMED), Poka-Yoke, and 5S methodologies in a manufacturing company in Lima, Peru, dedicated to producing fiberglass reinforced polyester (FRP) poles. The research seeks to demonstrate how the combination of these tools can improve Overall Equipment Effectiveness (OEE) and consequently increase the company's competitiveness.

The case study selected due to the need to optimize its production processes. Preliminary diagnostic data revealed that the company's main production line had an OEE of 38.85%, indicating poor efficiency, which leads to economic losses and limits the ability to meet market demand. The low OEE is driven by operational challenges identified in the production process. First, delays in material preparation, caused by a lack of timely availability and excessive reprocessing. Second, the absence of standardized procedures for mold changes leads to significant interruptions. Third, inefficient production planning causes resource misallocation and additional idle time. Finally, prolonged maintenance and repair times, due to the lack of a structured maintenance plan and insufficient inspections.

To address these challenges, an integrated model combining key continuous improvement tools is proposed. The TPM approach ensures that equipment is available and operates optimally through autonomous and preventive maintenance. The SMED methodology reduces changeover times, minimizing production interruptions. Poka-Yoke helps prevent operational errors, improving process quality, while 5S ensures workplace organization and cleanliness, increasing operational efficiency.

This article presents the implementation of a continuous improvement model in a manufacturing company, detailing the project phases, the indicators used, and the results obtained. The study adopts an experimental approach, measuring the impact of each intervention on OEE and comparing data before and after implementation. Previous research has explored the use of other continuous improvement models that, while effective in various contexts, have focused on indicators such as product quality or energy efficiency without achieving significant increases in OEE.

The validation of this model was carried out in a real production environment, ensuring the applicability of the results obtained and the possibility of replicating this approach in other manufacturing organizations. The main objective of this research is to demonstrate that adopting integrated continuous improvement tools can significantly increase OEE in a production line, aligning with international performance standards.

In an environment characterized by high competitiveness and economic constraints, the ability to optimize internal processes is essential to ensure long-term sustainability of companies. This study not only provides value to the studied organization but also offers a replicable model for other companies in the sector facing similar challenges in productivity and competitiveness.

This article is divided into the following sections: introduction, state of the art, contribution, validation, discussion, conclusions, and reference.

II. STATE OF THE ART

This state-of-the-art review analyses research in three keys areas for improving operational efficiency in FRP pole production: continuous improvement methodologies, performance indicators, and process optimization tools. The integration of these methodologies and tools enables a holistic approach to operational challenges, optimizing both time management and quality at each stage of the production process.

A. Methodology

The state of the art in industrial productivity improvement reveals a rich array of methodologies, each designed to address specific challenges in manufacturing processes. This section explores Lean Six Sigma, PDCA, Kaizen, and simulation techniques, with a particular focus on their practical applications in the context of tools such as Total Productive Maintenance (TPM), Single-Minute Exchange of Die (SMED), Poka-Yoke, and 5S.

Lean Six Sigma integrates the waste-elimination principles of Lean Manufacturing with Six Sigma's statistical tools to reduce process variability and enhance product quality [2]. In practice, this methodology employs tools like TPM to optimize equipment performance, SMED to minimize setup times, and 5S to ensure workplace organization. A notable example from the automotive industry illustrates its efficacy: a parts manufacturing plant achieved a 30% reduction in defect rates and a 15% improvement in OEE by implementing Lean Six Sigma [3]. However, the methodology demands significant expertise in statistical analysis and substantial resource investment, which can pose challenges for medium-sized enterprises with limited technical capacity. In the context of textile manufacturing, Lean Six Sigma could be applied to address unplanned downtime, potentially replicating the 17.08% OEE increase observed in a metalworking SME [4].

The PDCA (Plan-Do-Check-Act) cycle offers a structured framework for continuous improvement, emphasizing iterative problem-solving and process optimization [4]. By incorporating tools such as TPM, SMED, and Poka-Yoke, PDCA facilitates root cause analysis and error prevention. In a textile production case study, the application of PDCA resulted in a 20% reduction in waste and a 10% improvement in line efficiency through carefully planned interventions [5]. The methodology's strength lies in its systematic and repeatable nature, which supports sustained improvements, as evidenced by a 23% reduction in downtime in a similar industrial setting [4]. Nevertheless, its incremental approach may not be ideal for scenarios requiring urgent, large-scale transformations. For instance, in a metalworking SME, PDCA combined with TPM and SMED increased machine availability by 12.62%, from 71.13% to 83.75%, underscoring its practical value for gradual but measurable progress [4].

Simulation techniques provide a powerful means to optimize complex processes by virtually testing adjustments before implementation. Often paired with Lean tools like TPM and SMED, simulations enable risk-free experimentation. In a textile plant, simulation modelling reduced material handling times by 15% and increased throughput by 5%, demonstrating its value as a low-risk optimization tool [5]. Despite its proven efficacy, including a 13.28% OEE improvement in a textile screen-printing operation [5], the high initial costs of software and expertise can deter adoption in resource-constrained settings. For FRP pole production, simulations could validate a TPM-SMED model, potentially achieving a 23% reduction in downtime and a 35% decrease in setup times, as observed in a Peruvian textile study [5].

After a thorough evaluation of these methodologies, PDCA was selected as the foundation for this study due to its structured, iterative approach, which aligns seamlessly with the cyclical demands of textile manufacturing and the integration of TPM, SMED, Poka-Yoke, and 5S. The methodology's proven effectiveness in similar industrial contexts, such as a 10% efficiency increase in textile production lines [6] and a 12.62% improvement in machine availability in metalworking [4], supports its suitability for achieving sustainable OEE improvements in FRP pole production.

B. Solution model tools

The state of the art presents various tools that address specific problems in industrial processes. The adoption of lean manufacturing and maintenance methodologies provides a comprehensive strategy for enhancing operational efficiency in fiber-reinforced polymer (FRP) pole production.

Total Productive Maintenance (TPM) is a proactive maintenance approach that maximizes equipment reliability by involving operators in routine maintenance tasks such as cleaning, lubrication, and inspections. Other authors emphasize TPM's role in small and medium-sized enterprises (SMEs), noting that its implementation in a manufacturing SME reduced downtime by 20% through structured maintenance schedules and operator training [7]. Similarly, a study reported a 15% increase in conveyor belt availability in a case integrating TPM with Industry 4.0 technologies [8]. While TPM enhances equipment uptime and fosters a culture of ownership, its implementation requires significant training and cultural adaptation, which can strain resources in SMEs. In FRP pole production, TPM can mitigate frequent equipment failures, ensuring consistent output and potentially improving OEE by 10–20%, as evidenced in similar industrial settings.

Single Minute Exchange of Die (SMED) aims to minimize setup times, enabling rapid equipment changeovers and enhancing production flexibility. Research evidence suggests SMED's application in textile manufacturing, where digitized processes reduced changeover times, allowing manufacturers to adapt swiftly to diverse product demands [9]. In a Peruvian construction context, a research effort noted that SMED reduced non-contributory time by optimizing task transitions, achieving a 12% efficiency gain [10]. SMED's strength lies in its ability to increase throughput without additional capital investment, but it requires meticulous process planning, and poorly trained teams may face temporary disruptions. For FRP pole production, SMED can streamline mold changeovers for varying pole specifications, reducing idle time and potentially boosting OEE by 10–15%, as seen in comparable industries.

Poka-Yoke, or mistake-proofing, employs simple mechanisms to prevent human errors, thereby improving product quality. A case study documented Poka-Yoke's use in the textile industry, where devices such as Andon lights and metal detectors reduced defect rates by 5%, saving approximately 7258.73 rupees monthly in rework costs [11]. Other findings also applied Poka-Yoke in construction to ensure task accuracy, contributing to a 7% reduction in errors [10]. In pole production, Poka-Yoke can ensure precise mold alignment or detect material inconsistencies, minimizing defects. While cost-effective and impactful, Poka-Yoke is limited to specific error types and cannot address broader systemic issues. Its implementation can improve OEE's quality component by 3–5%, as demonstrated in textile and construction applications.

The 5S methodology—Sort, Set in Order, Shine, Standardize, and Sustain—promotes workplace organization to enhance operational efficiency. Yashini reported that 5S implementation in textile manufacturing reduced unproductive time by 15% by streamlining workstations and improving tool accessibility [11]. Similarly, empirical evidence supports that 5S in a Peruvian construction firm reduced material search times, contributing to a 10% efficiency improvement [10]. In FRP pole production, 5S can ensure that materials and tools are readily accessible, critical for labor-intensive processes. However, sustaining 5S requires continuous reinforcement, and without regular audits, benefits may diminish. Its adoption can enhance OEE by 10–20% through improved workflow efficiency.

The integrated application of these tools offers a cohesive approach to tackling inefficiencies OEE indicator and FRP pole production. By leveraging their practical strengths and addressing implementation challenges, these tools hold significant potential to enhance equipment reliability, process flexibility, and product quality, aligning closely with the operational needs of the Peruvian manufacturing sector.

C. *Performance Indicator*

In manufacturing, selecting appropriate performance indicators is critical for accurately assessing process efficiency and guiding improvement initiatives. The Overall Equipment Effectiveness (OEE) metric has emerged as a comprehensive tool for evaluating equipment utilization by integrating availability, performance, and quality [12]. Research on multiproduct production systems [12] demonstrated significant improvements in production effectiveness, with OEE values increasing from 0.58 to 0.73 in a case study involving a household paper manufacturer. This underscores OEE's ability to identify operational losses, such as downtime (reduced by 21.64% post-intervention) and quality defects, while providing a holistic view of equipment performance. However, studies highlight limitations in OEE's application for complex environments, such as multiproduct lines, where bottlenecks and process variability complicate measurements [12].

Key Performance Indicators (KPIs) offer flexibility by targeting specific operational aspects, such as cycle time or maintenance cost efficiency. A survey of Belgian industries [13] revealed that 78% of companies monitored maintenance costs as a percentage of total manufacturing costs, yet only 10% of decisions were directly driven by KPI insights, indicating a gap between data collection and actionable improvements. This fragmented approach can limit systemic optimization, as KPIs often focus on isolated metrics rather than interdependencies between processes.

Throughput and Lead Time are particularly relevant in lean-oriented environments. A Lean Six Sigma implementation in a paper production case study [14] demonstrated a 41.8% reduction in Lead Time (from 43,200 to 25,115 seconds) and an increase in Process Cycle Efficiency from 23.4% to 40% through value stream mapping and waste reduction. Such examples emphasize the importance of aligning indicators with operational goals, Lean methodologies prioritize Lead Time to enhance customer responsiveness.

Despite the strengths of alternative metrics, OEE was selected for this study due to its ability to address the three core challenges in FRP pole manufacturing: equipment downtime, speed losses, and quality defects. Empirical evidence from capital-intensive industries [12,14] supports OEE's effectiveness in quantifying losses holistically, enabling targeted interventions. This aligns with the research objective of maximizing competitiveness through systematic efficiency gains, making OEE the most robust indicator for evaluating the integrated TPM, SMED, Poka-Yoke, and 5S model.

D. *Importance and Limitations*

The state of the art highlights the importance of using PDCA, OEE, and tools such as TPM, SMED, Poka-Yoke, and 5S to comprehensively address operational challenges in industrial production. PDCA offers a structured approach that facilitates problem identification and resolution through continuous improvement, allowing rigorous process control [4]. OEE, as the primary indicator, is crucial for its ability to comprehensively measure operational efficiency by considering availability, performance, and quality [15].

The selected tools complement these approaches:

- TPM ensures equipment availability through preventive maintenance [16].
- SMED reduces downtime by optimizing mold changeovers [16].
- Poka-Yoke prevents errors at the source [11].
- 5S ensures an organized and efficient workplace environment [16].

The integration of methodologies such as SMED, TPM, and 5S offers significant operational benefits, but their practical application faces critical limitations. For instance, SMED implementation requires substantial financial and technical resources, with studies showing that 55% of SMEs abandon Lean practices due to budget constraints, particularly in industries like plastics manufacturing [17]. Similarly, TPM demands rigorous maintenance protocols and workforce training, which can strain organizational capacity. While Spanish manufacturing firms achieved a 30% reduction in unplanned downtime through TPM, sustaining these results necessitated continuous investment in employee upskilling, a challenge in resource-limited settings [17].

The 5S methodology, though cost-effective, struggles with long-term sustainability. Research highlights that 55% of SMEs failed to maintain 5S practices beyond initial implementation phases due to lapses in employee discipline and leadership commitment [17]. Even in cases where productivity improved by 20–48%, inconsistent adherence to standardization and cleaning protocols eroded gains over time [18].

OEE, while a robust metric for equipment effectiveness, overlooks contextual factors such as organizational culture. For example, Spanish firms observed that OEE improvements from Lean tools did not correlate with employee motivation, which indirectly affected sustained productivity [17]. Additionally, methodologies like PDCA face cultural resistance; longitudinal studies noted that iterative problem-solving frameworks prolonged adaptation periods by 3–6 months in structured industries, delaying tangible outcomes [17].

These limitations underscore the need for context-sensitive strategies, particularly in regions like Peru, where industrial dynamics amplify implementation risks. Balancing methodological rigor with adaptive change management—such as phased training and leadership engagement—is critical to mitigating these challenges.

III. CONTRIBUTION

This paper proposes an innovative model that integrates four key continuous improvement techniques: SMED, TPM, Poka Yoke, and 5S. These methodologies, widely applied in operations management, have proven effective in enhancing productivity, reducing changeover times, and optimizing workplace organization. Through an exhaustive state-of-the-art review, this management model has been developed by adapting and combining these techniques for application in an FRP pole manufacturing company in Peru.

The proposed model is structured into five sequential steps, designed to comprehensively address the company's operational challenges. Each step is intended to enhance specific aspects of production, from the initial evaluation to final validation, ensuring an effective and sustainable implementation of the proposed improvements. The process begins with a detailed assessment of the plant's current situation, followed by standardizing the work environment, improving equipment availability, optimizing production capacity, and culminating in the validation and monitoring of the obtained results.

In the case study of the pole manufacturing company, the implementation model is proposed through a series of steps described in the following sections.

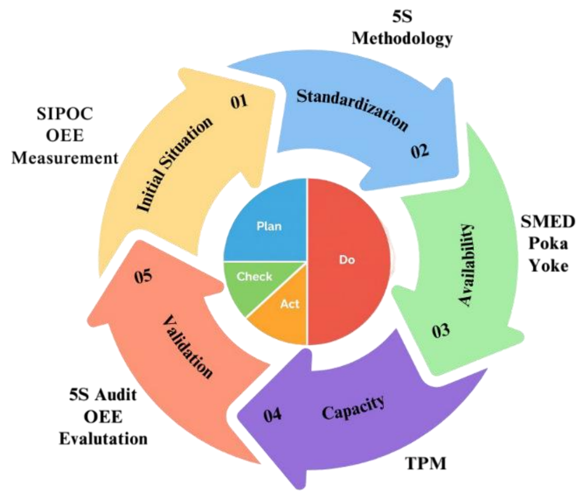

Fig. 1 Model Diagram

A. *Model Tools Implementation*

1) 5S Implementation: The 5S methodology focuses on organization, cleanliness, and standardization of the workplace to enhance operational efficiency and reduce waste [18].

- *Sort (Seiri):* In this phase, unnecessary items were removed from the work areas. The team conducted a comprehensive inventory of tools and materials, eliminating non-essential items for daily operations. This freed up space and facilitated the identification of key resources during the production process.
- *Set in Order (Seiton):* The team arranged necessary items systematically to ensure quick and easy access. Visual management techniques, such as labelled storage areas and designated tool placements, were implemented to minimize search time and enhance workflow efficiency
- *Shine (Seiso):* Daily cleaning routines were established to maintain workstations in optimal conditions. Each operator was assigned a specific area, and control boards were installed to record completed tasks and highlight any issues encountered during inspections.

Fig. 2 Shine Execution

- *Standardize (Seiketsu):* Standard operating procedures and manuals were developed to ensure long-term organization and cleanliness. These documents included checklists and periodic audits to guarantee adherence to best practices.
- *Sustain (Shitsuke):* Finally, a culture of discipline and continuous improvement was promoted among employees. Periodic training sessions and surprise audits were conducted to assess compliance with 5S. Employees were also incentivized through recognition programs for maintaining an organized and clean workspace.

2) SMED Implementation: At this stage, the SMED technique was integrated to significantly reduce setup and changeover times in the manufacturing of FRP poles. SMED is a well-established technique that enables quick machine changeovers, reducing downtime and increasing production flexibility. The primary objective of SMED is to minimize mold and tool change times, thus optimizing equipment availability and boosting production capacity [19].

- *Changeover Time Analysis:* Current mold change times on the winding machine were recorded, identifying both internal and external tasks that caused significant delays. During this analysis, it was observed that mold changes required approximately 13 minutes per cycle, negatively impacting productivity.
- *Standardization of Changeover Processes:* To optimize changeovers, tasks that could be performed while the machine was running (external tasks) were distinguished from those requiring machine stoppage (internal tasks). A standardized sequence of activities was designed to ensure that operators had all necessary tools available before the changeover, eliminating unnecessary delays.

Fig. 3 Pilot Test for Mold Change

- *Implementation of Quick Adjustment Devices:* Quick-adjustment tools and support were introduced to minimize the time required for mold assembly and disassembly. Additionally, pilot tests were conducted with a small group of operators to refine the methodology before full-scale implementation. Practical training sessions were also carried out, where operators practiced mold changes using newly developed techniques and tools.

Fig. 4 Second pilot test for mold transport device

3) TPM Implementation: It aims to ensure equipment availability and efficiency through the application of preventive and autonomous maintenance, involving both technical and operational staff [16].

- *Identification of Critical Equipment:* The first step involved analysing the equipment used in production, prioritizing those with the highest impact on productivity, such as the winding machine. These machines were evaluated based on their breakdown history and downtime records to focus preventive maintenance efforts. Detailed monitoring records were developed to track daily performance and failure frequency.

Fig. 5 Maintenance Training

- *Implementation of Autonomous Maintenance:* Operators were trained to perform basic maintenance tasks, such as cleaning and visual inspections. This approach aimed to reduce reliance on specialized technicians for minor interventions. Daily checklists were introduced to ensure that operators maintained their equipment in optimal conditions, fostering a greater sense of responsibility.

- *Design of a Preventive Maintenance Plan:* A periodic maintenance schedule was established for performing more complex tasks, such as critical part replacements and mechanical adjustments. This planning was aligned with production schedules to minimize disruptions. Additionally, a monitoring system was designed based on key indicators, such as Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR), to evaluate maintenance effectiveness.

4) Poka-Yoke Implementation: Poka-Yoke focuses on preventing human errors through the design of systems and devices that eliminate defects in production processes.

- *Identification of Critical Error Points:* A process mapping exercise was conducted to identify activities prone to errors, such as labelling and packaging of poles. These errors caused rework and delays, affecting final product quality and customer satisfaction.
- *Design of Error Prevention Devices:* Simple mechanisms such as marked meters were implemented to measure each input, ensuring that the poles and their components were transported and placed correctly. Additionally, visual devices were incorporated to indicate the correct mold quantity before starting the winding process.
- *Staff Training on the Use of Poka-Yoke:* Operators received specialized training on the use of Poka-Yoke devices and their importance in error prevention. Furthermore, a culture of continuous improvement was promoted, encouraging employees to propose new ideas to prevent failures and optimize processes.

B. Indicators and Formulas

To evaluate the performance and efficiency of the implementation of the proposed management model in an FRP pole manufacturing company, the following key indicators have been selected.

1) OEE: This indicator is calculated by multiplying equipment availability, performance and quality, expressed as a percentage. Its objective is to measure the overall efficiency of the equipment. The formula is:

$$OEE = Availability \times Performance \times Quality. \quad (1)$$

TABLE I
WORLD CLASS OEE INDICATOR

N°	World Class OEE		
	Description	Rating	Italic
1	Significant economic losses occur. Very low competitiveness	Deficient	OEE < 65%
2	Economic losses occur. Low competitiveness.	Regular	65% ≤ OEE < 75%
3	Slight economic losses. Slightly low competitiveness.	Acceptable	75% ≤ OEE < 85%
4	Falls within World Class values. Good competitiveness	Good	85% ≤ OEE < 95%
5	World Class values. High competitiveness.	Excellent	95%≤OEE≤100%

2) Availability: The factor is calculated as the time equipment is operational compared to the total planned time, expressed as a percentage. Its objective is to measure the efficiency of equipment uptime. The formula for calculating equipment availability is:

$$\text{Availability}= \frac{\text{Operating Time}}{\text{Total Planned Time}}. \quad (2)$$

3) Performance: The performance factor is determined by measuring the speed at which machines operate compared to their maximum operational capacity. The formula for calculating performance is:

$$\text{Performance}= \frac{\text{Ideal Cycle Time} \times \text{Total Pieces}}{\text{Total Planned Time}}. \quad (3)$$

4) Quality: The quality factor determines the number of manufactured parts that meet quality standards, defining the percentage of pieces that successfully proceed to the next manufacturing process. The formula for calculating quality is:

$$\text{Quality}= \frac{\text{Good Quality Pieces}}{\text{Total Planned Time}}. \quad (4)$$

2) Setup efficiency: Setup efficiency is calculated by comparing the standard setup time with the actual setup time, expressed as a percentage. Its objective is to assess the effectiveness of time reduction techniques such as SMED. The formula for calculating setup efficiency is:

$$\text{Setup Efficiency}= \frac{\text{Previous Time} - \text{Current Time}}{\text{Previous Time}}. \quad (5)$$

2) Cycle time: Cycle time is determined to understand how long it takes to produce a single unit of product. The formula for calculating cycle time is:

$$\text{Cycle Time}= \frac{\text{Total Operating Time}}{\text{Number of Units Produced}}. \quad (6)$$

IV. VALIDATION

A. Current Situation Phase

1) SIPOC Implementation: The first step in validating the model consisted of analysing the current state of the FRP pole production line using the SIPOC (Supplier, Input, Process, Output, Customer) diagram. This tool allowed for mapping and documenting each of the key stages of the production process, from the supply of raw materials to the delivery of the final product. By clearly identifying the elements influencing the process, it was possible to obtain a comprehensive view of the critical points affecting operational efficiency.

2) OEE Measurement: The OEE measurement during the initial diagnostic phase establishes a baseline to evaluate the impact of each intervention implemented in the production system. OEE was calculated by multiplying three key components: Availability, Performance, and Quality. Data collection focused on the winding machine, identified as the production bottleneck, and was carried out through time studies, direct observation, and daily operational logs over a five-month period.

- *Availability:* This component was computed by comparing actual operating time against scheduled production time, discounting planned stops such as breaks or preventive maintenance.
- *Performance:* It was assessed by dividing the actual production output by the theoretical maximum output, highlighting delays due to inefficient changeovers and micro stoppages.
- *Quality:* Measured the ratio of conforming products to total products produced, capturing the impact of rework and process errors.

The initial OEE was 38.85% with this result the diagnostic allowed for the precise quantification of losses in each OEE component and revealed that the greatest opportunity for improvement was in performance, which was significantly below world-class standards. These insights provided a solid foundation for testing the effectiveness of each Lean tool within the integrated model, allowing comparative analysis before and after implementation.

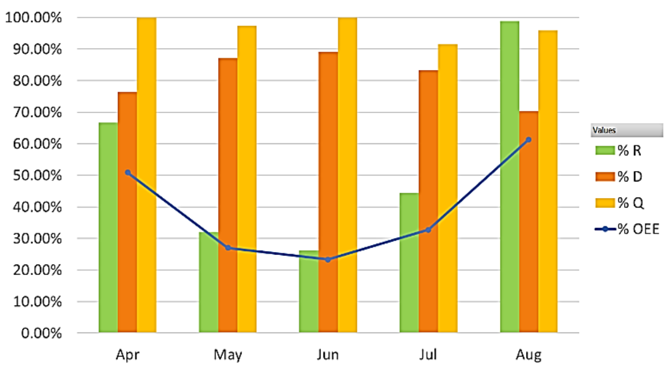

Fig. 6 Initial OEE Calculation

TABLE II
OEE MEASUREMENT

Mth.	Measurement			
	% OEE	% A	% P	% Q
Apr	50.91%	66.67%	76.36%	100.00%
May	27.00%	32.08%	87.12%	97.22%
Jun	23.33%	26.17%	89.17%	100.00%
Jul	32.74%	44.37%	83.24%	91.47%
Aug	61.35%	98.86%	70.20%	95.90%
Avg.	38.85%	55.22%	80.95%	95.00%

B. Standardization Phase

1) 5S Methodology: The next step in the validation model was the implementation of the 5S methodology, a key tool for achieving standardization and organization in the production plant. The focus of 5S was on improving the work environment by facilitating access to tools and equipment, reducing search times, and optimizing space usage in the production area. The five phases of this methodology were implemented:

- Sort, where essential materials were identified and separated.
- Set in Order, with proper placement and labelling of tools and equipment.
- Shine, which included daily routines to maintain a safe and efficient work environment
- Standardize, where detailed operating procedures were created to maintain order and cleanliness.
- Sustain, with the implementation of audits and incentive programs to ensure that improvements are maintained in the long term.

C. Availability Phase

1) SMED Implementation: This tool was key in reducing mold change times, a critical process in the production of FRP poles. Through the planning and standardization of mold changes and the creation of two mobile two-wheeled devices, several changeover activities were externalized, reducing downtime by more than 30%.

2) Poka-Yoke Implementation: This step of validation focused on improving process quality, specifically in the precise dosing of inputs in the resin, peroxide, and cobalt mixture. A measuring device was designed to ensure accurate material proportions, eliminating human errors and improving production consistency. These advancements resulted in a reduction of mixing errors and an increase in the quality of the final product.

D. Capacity Phase

1) TPM Implementation: To ensure operational continuity and improve the production line's capacity TPM practices were implemented. The first step was a detailed evaluation of the equipment's condition, where components with the highest probability of failure were identified, prioritizing corrective and preventive maintenance interventions.

Staff was trained in autonomous maintenance, promoting direct responsibility of operators over their machines. This enabled them to perform basic maintenance tasks, such as component lubrication and equipment calibration, reducing reliance on specialized personnel. Additionally, a continuous monitoring system for downtime and failures was implemented, helping to detect failure patterns and take preventive action before critical stoppages occurred.

E. Validation Phase

1) 5S Audits and OEE Indicator Updates: The final step of the model involved continuous validation through periodic 5S audits and updating OEE indicators. The 5S audits verified that the order, cleanliness, and organization standards established in the initial phases were maintained over time, ensuring the sustainability of improvements. Moreover, the audits included active staff participation, fostering a culture of continuous improvement within the plant.

Finally, the OEE indicators were updated and compared with the initial values, reflecting significant improvements in availability, performance, and production quality. These results confirmed the effectiveness of the integrated model of

TPM, SMED, Poka Yoke, and 5S in enhancing operational efficiency and the competitiveness of the FRP pole production line.

Below is the diagram illustrating the improvement applied to the process.

TABLE III
COMPARISON OF INDICATORS BEFORE – AFTER MODEL IMPLEMENTATION

Impact assessment of the improvement [a]		
Indicator	Before Implementation	After Implementation
Overall Equipment Efficiency	38%	80.56%
Cycle Time (min)	82	67
Setup Times (min)	5	2.5

[a] The improvements shown in this table were achieved over a 6-month period.

TABLE IV
ECONOMIC IMPACT AFTER MODEL IMPLEMENTATION

Impact Assessment of the Improvement (months)			
Indicator	Before Implementation	After Implementation	% Reduction
Minutes Lost Due to Setup and Maintenance	1605	855	47%
Units Lost Due to Low OEE Index (in soles)	29 (S/ 18 360)	15 (S/ 10 200)	49%

[a] Economic impacts were calculated based on a 12-month evaluation period considering direct costs associated with downtime and maintenance activities in the pole production process

V. DISCUSSION

This section analyses the results obtained after implementing the improvement model based on the PDCA cycle and the TPM, SMED, Poka-Yoke, and 5S tools in the FRP pole production line at the MAGRA SAC plant. The objective is to evaluate the impact of these methodologies on operational efficiency, particularly in terms of improving OEE, a key indicator measuring availability, performance, and quality of the production process.

The plant faced significant issues related to low equipment availability and prolonged downtime, which affected production capacity. Through the implementation of TPM, a notable increase in equipment availability was achieved, reducing unplanned downtime through preventive maintenance. This result aligns with previous research that has demonstrated TPM's effectiveness in improving equipment reliability in industrial environments [20]. Additionally, the structured PDCA approach allowed for identifying the main causes of inefficiencies, resulting in precise and effective interventions.

One of the critical challenges was the excessive time required for mold changes, which reduced equipment performance. The application of SMED reduced changeover times by 30%, increasing the plant's flexibility and responsiveness. This was particularly important in an environment where production process interruptions represented a significant loss of time and resources. The effectiveness of SMED in improving operational efficiency has been confirmed in previous studies [6], and the results obtained at the FRP pole production line align with these conclusions.

Regarding product quality, the integration of Poka-Yoke reduced defects by preventing human errors in critical phases of the production process. Improved precision in manufacturing FRP poles not only decreased the number of reworks but also increased customer satisfaction by ensuring that products consistently met established quality standards. The visual control devices installed to prevent errors proved effective, validating the importance of Poka-Yoke in production environments where mistakes can significantly impact final quality [11].

Furthermore, the implementation of 5S significantly improved the work environment by promoting organization, cleanliness, and discipline. This not only had a positive impact on team morale but also facilitated access to tools and materials, reducing unproductive time. Although 5S is recognized for its ability to generate incremental improvements in workplace organization, its long-term sustainability depends on employee commitment and company leadership [18].

The results obtained at the MAGRA SAC plant are consistent with previous studies indicating that OEE is a key indicator for identifying areas of improvement in production processes. In this case, OEE increased significantly, confirming that integrating TPM, SMED, Poka-Yoke, and 5S enhances availability, performance, and quality in production. Despite these achievements, challenges such as the need for staff training and resistance to organizational change initially delayed improvements. However, these obstacles were overcome as the team adapted to the new practices.

A. *Indicators:*

1) 1%: Percentage measuring overall equipment efficiency, calculated as the product of Availability, Performance , and Quality.

2) 2%: Percentage of time the equipment is available for operation compared to the total planned time. It reflects losses due to downtime, such as maintenance or unexpected stoppages.

3) 3%: Percentage of manufactured products that meet quality standards in relation to the total number of products produced. This indicator evaluates the efficiency of the equipment in producing defect-free parts or products.

4) 4%: Percentage measuring the speed at which equipment is producing relative to its maximum theoretical speed or optimal capacity.

B. *Models and their result*

1) 13/600 Pole: This model has an OEE of 80.5%, with availability of 88.58%, quality of 97.24%, and performance of 93.76%. It reflects strong performance, especially in quality.

2) 8/300 Pole: This model stands out with an OEE of 84.23%, availability of 86.69%, quality of 97.82%, and an excellent performance of 99.60%. The high-performance levels indicate efficient and effective production.

3) 12/300 Pole: This model shows a lower OEE of 72.64%, with availability of 91.92%, quality of 94.95%, and performance of 83.31%. Despite its lower OEE, availability and quality are competitive, suggesting areas for improvement in performance.

4) 9/200 Pole: With an OEE of 80.77%, availability of 87.67%, quality of 97.51%, and performance of 94.75%, this model demonstrates balanced performance, maintaining high standards in quality and performance.

The following table presents the comparative analysis of performance indicators for different business products:

TABLE V
COMPARISON OF PERFORMANCE INDICATORS IN THREE BUSINESS PRODUCTS

N°	Indicator				
	Types	OEE %	A %	Q %	P %
1	13/600	80.50%	88.58%	97.24%	93.76%
2	8/300	84.23%	86.69%	97.82%	99.60%
3	12/300	72.64%	91.92%	94.95%	83.31%
4	9/200	80.77%	87.67%	97.51%	94.75%
	AVG	79.54%	88.71%	96.88%	92.86%
	VAR	0.0018	0.00038657	0.0001284	0.00327
	STD	0.0424	0.01965	0.0113	0.0571

C. Statistical Analysis

The statistical analysis results of key indicators across four locations are presented, highlighting how variance and standard deviation reflect the consistency of the implemented model.

1) OEE: The results show an average of 79.54%, which is a positive indicator of operational efficiency within the company. The low variance of 0.00180 and a standard deviation of 0.0424 suggest that the data is consistent and that fluctuations in OEE are minimal. This reflects stable performance in production lines and the effectiveness of the implemented strategies. Maintaining this level of OEE could lead to additional improvements in productivity and efficiency, which is crucial for competitiveness in the sector.

2) Availability: The results for the availability indicator show an average of 88.71%, indicating a high level of availability in production lines. The variance of 0.00038657 and a standard deviation of 0.01965 demonstrate that the values are quite consistent, with minimal variations in performance. This suggests that the company has successfully established an efficient and reliable production environment. Maintaining and improving this level of availability not only contributes to increased OEE but also strengthens the company’s ability to meet market demand effectively.

3) Performance: The quality indicator results show a notable average of 92.86%, indicating that the company is achieving high product quality standards. However, with a variance of 0.00327 and a standard deviation of 0.0571, there is greater data dispersion compared to other indicators. This suggests that while most products meet quality standards, there are still opportunities to improve consistency and reduce variability in production.

4) Quality: The results for the performance indicator show an outstanding average of 96.88%, reflecting exceptional efficiency in utilizing production resources. With a variance of 0.00012839 and a standard deviation of 0.0113, the data is highly consistent and exhibits minimal variation in performance. This indicates that the company is not only maintaining high performance levels but is also in a strong position to further optimize its processes.

VI. CONCLUSIONS

The implementation of the PDCA methodology, along with TPM, SMED, Poka-Yoke, and 5S tools, has proven to be effective in significantly improving operational efficiency in FRP pole production. The study results indicate that combining these tools optimizes key processes in the plant, enhancing the three components of OEE: availability, performance, and quality.

The application of TPM significantly reduced unplanned downtime through efficient preventive maintenance. The increase in equipment availability allowed for better resource utilization and greater responsiveness to production demand. This was crucial for increasing operating time and equipment reliability. The use of SMED reduced mold change times by 30%, increasing operational flexibility and effective production time. The plant was able to reduce time losses during batch changes, leading to a significant improvement in process performance, bringing it closer to the plant’s maximum capacity.

The implementation of Poka-Yoke as an error prevention system minimized production defects, thereby improving the quality of FRP poles. The reduction in rework and waste not only optimized resources but also enhanced customer satisfaction by ensuring consistent, high-quality products. The 5S methodology contributed to maintaining a clean, organized, and efficient work environment, reducing search times and losses associated with disorganization. However, sustaining pthese improvements requires continuous commitment from personnel to maintain discipline.

OEE was confirmed as a key indicator for measuring equipment effectiveness. Throughout the study, improvements in availability, performance, and quality were observed, validating its capability to provide a comprehensive view of operational efficiency within the plant. Using this indicator enabled the identification of specific areas for improvement and the monitoring of intervention impacts.

Although the methodology was effective, some initial challenges were identified, such as the need for staff training and resistance to organizational change. As the team became familiar with the new practices, these barriers were overcome, but ongoing focus on continuous training and motivation will be necessary to ensure the sustainability of improvements.

In conclusion, this study demonstrates that implementing PDCA alongside TPM, SMED, Poka-Yoke, and 5S is an effective strategy for improving efficiency and quality in industrial production. The proposed model not only optimized equipment availability, performance, and quality but also enhanced the plant's operational competitiveness. Future research could focus on optimizing staff training and developing strategies to sustain the improvements achieved over the long term, particularly in the implementation of 5S.

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