Empirical study on OEE optimization in a Peruvian flexographic printing SME: a Lean-TPM model that integrates 5S and SMED

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Abstract-*The flexographic printing industry plays a crucial role in the packaging sector; however, many companies in emerging markets face low Overall Equipment Effectiveness (OEE), primarily due to long setup times, unplanned downtime, and process inconsistencies. Previous studies have addressed these issues through isolated applications of Total Productive Maintenance (TPM), One Minute Die Change (SMED), and 5S. However, little research has integrated these tools into a unified model tailored to the industry's challenges. This study developed a structured Lean-TPM model that combines 5S, SMED, and TPM to improve OEE in a Peruvian flexographic printing SME. The model was validated through pilot implementations and simulation using Arena software. The results showed an increase in OEE from 59.91% to 70.84%, a 29.05% reduction in setup time, and a 28.26% decrease in the defect rate. These improvements demonstrate the model's effectiveness in optimizing performance while ensuring financial sustainability. This research provides a replicable framework for similar industries. Future studies should explore AI applications to further improve predictive maintenance and operational efficiency in dynamic manufacturing environments.*

Keywords: Process standardization, Setup time reduction, Operational performance, Continuous improvement, Lean manufacturing.

I. Introduction

The flexographic printing sector plays a fundamental role in the packaging and label industry, areas that have experienced significant growth due to the increasing demand for customized products. This sector is essential to various markets, such as food, beverages, and consumer products, where production quality and efficiency are critical factors for maintaining competitiveness. Globally, the operational efficiency of equipment, measured by the Overall Equipment Efficiency (OEE) indicator, has been established as a key standard for assessing industrial productivity [1]. An OEE below 85% is considered insufficient by international standards, negatively impacting profitability and competitiveness.

In Peru, the graphic industry, which includes flexographic printing, contributes significantly to national economic development. In 2022, this sector represented 1.3% of the manufacturing Gross Domestic Product (GDP), standing out as a key player in exports, especially in the production of packaging for international markets [2]. In addition, it generates thousands of direct and indirect jobs, contributing to the growth of the national economy [3]. However, many Peruvian companies face significant challenges in the operational efficiency of their equipment, which limits their ability to compete in domestic and international markets.

In this context, the case study is a company specializing in the printing of paper packaging, which recorded an average OEE of only 59.91% in 2023, significantly below the international standard of 85%. This poor performance is due to long setup times, unplanned downtimes, and a lack of standardization in operations, generating estimated economic losses of 190,046 soles annually, equivalent to 8.39% of total sales. These figures underscore the urgency of implementing strategies to optimize the operational efficiency of its processes.

Methodologies such as Total Productive Maintenance (TPM) and Lean tools such as SMED and 5S have proven effective in improving OEE in various manufacturing sectors [4], [5]. Reductions of up to 30% in setup times have been reported using SMED [6], while other studies have shown 12% increases in equipment availability thanks to TPM [1]. However, the integrated application of these methodologies remains limited in emerging markets such as Peru, which represents an important opportunity to innovate in the management of production processes.

Unlike previous approaches that have addressed these methodologies in isolation, this study proposes an integrated model that combines TPM, SMED, and 5S, tailored to the needs of the flexographic sector. This model seeks not only to optimize OEE in the case study but also to establish a replicable framework for other local industries with similar challenges. By addressing issues of availability, performance, and quality, this approach has the potential to contribute to the development of continuous improvement strategies that strengthen business competitiveness in emerging markets such as Peru.

II. Literature review

A. Overall Equipment Effectiveness (OEE) and its impact on industry productivity

Overall equipment effectiveness (OEE) is widely recognized as a key indicator for assessing productivity and operational efficiency in the manufacturing industry. This indicator, which integrates the components of availability, performance, and quality, allows identifying critical areas for improvement in production processes [7]. An OEE below 85% is considered significantly lower than international standards, which affects the profitability and competitiveness of companies [1], [8].

In the context of the flexographic printing industry, OEE is used to identify specific inefficiencies such as long setup times and unplanned downtime [9], [10]. The implementation of Total Productive Maintenance (TPM) has been shown to substantially improve equipment availability [1], while a systematic approach to OEE improvement leads to sustained productivity increases in printing industries with high order variability [11].

However, this industry faces unique challenges due to the high variability of manufactured products and frequent batch changes. These characteristics make OEE measurement and improvement difficult in this sector, highlighting the need for strategies tailored to its specific characteristics [12].

B. Implementation of the 5S Methodology: Impact on Efficiency and Work Environment

The 5S methodology is a continuous improvement tool widely adopted in the manufacturing industry to optimize the work environment and eliminate waste. This approach, structured in five stages (sort, sort, clean, standardize, and sustain), contributes significantly to operational efficiency and industrial safety [13]. In environments where multiple product references are handled, such as in the printing industry, its application facilitates the organization of materials, tools, and documents necessary for rapid format changeover [14].

In the flexographic printing sector, where speed and cleanliness are essential to avoid printing defects, the 5S methodology has proven effective in reducing downtime and quality defects related to the order of the work environment [15], [16]. However, despite its usefulness, there are limitations in its sustained implementation due to staff turnover and resistance to change in some companies in the sector, which makes it difficult to consolidate this practice as an operating standard [17]. To overcome these barriers, it is essential to combine 5S with complementary tools that allow managing the variability inherent in sectors such as flexography.

C. Setup Time Optimization: Analysis of SMED Methodology in Industry

Reducing setup times is a critical aspect in improving productivity in manufacturing, particularly in industries with high variability in production batches, such as flexographic printing. The SMED (Single-Minute Exchange of Die) methodology focuses on minimizing tool changeover and machine setup times, resulting in increased operational efficiency and reduced downtime [6], [18].

Successful implementation of SMED enables increased production flexibility, which is crucial in high-demand environments where frequent batch changes are common. This also contributes to reduced operating costs and improves responsiveness to changing customer needs [19], [20].

However, SMED implementation may face resistance in organizations with an established culture that is not focused on continuous improvement and process optimization [21].

D. Total Productive Maintenance (TPM): A Comprehensive Approach to Continuous Improvement in Industry

Total Productive Maintenance (TPM) has been consolidated as a comprehensive strategy aimed at the continuous improvement of operational efficiency, by involving both technical and operational personnel in the management of equipment maintenance and care [1], [22]. Its implementation has shown positive results in various industrial sectors, including the flexographic industry, where it has allowed to reduce mechanical failures and downtime, optimizing the overall performance of the equipment (OEE) [1], [12]. In a study applied to three flexographic presses, the adoption of TPM showed a significant improvement in operational availability, by decreasing both the frequency and duration of stops [1].

However, its adoption is not without challenges; the main barriers include resistance to change, lack of technical training of staff and the need to establish constant monitoring processes to ensure its sustainability [11], [22]. Despite these difficulties, the structured approach of TPM positions it as a key tool within operational excellence methodologies, especially when integrated with Lean practices in manufacturing environments [4].

E. Proposal for an integrated model

Despite the progress achieved with these methodologies, most studies have focused on their application in isolation, leaving a gap in the integration of tools such as TPM, SMED and 5S. Several works have pointed out that, although these methodologies are effective individually, their combination could simultaneously address problems related to availability, performance and quality, representing an important opportunity for continuous improvement in sectors such as flexographic printing [14], [21].

This study proposes an integrated model that combines the strengths of these tools, adapting them to the specificities of the flexographic sector in emerging markets. This approach not only seeks to optimize OEE but also establish a replicable framework that overcomes the limitations associated with the high variability and customization of production processes in the graphic arts industry.

III. METHODOLOGY

A. Basis of contribution (knowledge gap)

The main contribution of this research lies in the integration of widely recognized methodologies, such as TPM, SMED, and 5S, into the flexographic industry. This approach seeks to address three key shortcomings. The first is empirical, as studies related to OEE improvement in the flexographic industry are limited, especially in emerging markets such as Peru, where operating conditions and resources differ from those in developed countries. The second is methodological, given that most research has explored these methodologies in isolation, without considering their integration to simultaneously address issues of availability, performance, and quality. Finally, there is a contextual shortcoming, as companies in emerging markets face technical and financial constraints that hinder the implementation of models designed for more advanced industrial environments. This model proposes a comprehensive and replicable solution to maximize OEE in Etiquetas y Envolturas SAC, with potential for application in other industries with similar characteristics.

B. Comparison with previous models

To contextualize the contribution of this research, the proposed model was compared with five key studies selected for their relevance to improving OEE and operational efficiency. **Table 1** summarizes the main differences in scope and tools implemented. Unlike previous approaches, the proposed model integrates methodologies such as 5S, SMED, and TPM into a single framework, validated through simulation, allowing for a more robust approach adaptable to the specific needs of the flexographic industry.

C. General description of the contribution

The proposed model's main objective is to improve OEE through the sequential integration of complementary methodologies: 5S, SMED, and TPM. This approach combines continuous improvement strategies with advanced maintenance tools, comprehensively addressing issues of availability, performance, and quality. **Figure 1** presents the model's general structure, which begins with data collection (input), includes the implementation of selected tools, and ends with a validation process based on simulation and results analysis (output). This workflow ensures that improvements are sustainable, verified, and adapted to the specific context of the Peruvian flexographic industry.

TABLE I
COMPARATIVE TABLE OF THE COMPONENTS OF THE PROPOSED MODEL VS. LITERATURE REVIEW

	Improving energy efficiency in flexographic printing using Lean and AI techniques: a case study (Abusaq et al., 2023)	Improving overall equipment efficiency in the automotive parts manufacturing industry (Adithya, 2021)	The implementation of Lean Manufacturing to increase productivity in a textile company (Rodríguez et al.)	Methodology for calculating the overall effectiveness of equipment in the context of Industry 4.0 (Aleš et al., 2019)	Implementation of Lean Manufacturing to improve productivity in SMEs in the graphic sector (Alfonso et al., 2022)	Proposed model to increase OEE in the flexographic industry (Reynaga & Chavez, 2024)
Applied Sector	Flexography	Automotive	Textile	Industry 4.0	Graphic	Flexography
5S	✓	✓	✓	✗	✓	✓
SMED	✓	✓	✗	✗	✓	✓
TPM	✓	✓	✓	✓	✗	✓
Validation by simulation	✗	✗	✗	✓	✗	✓
Case studies	✓	✓	✓	✓	✓	✓
OEE as a metric	✓	✓	✗	✓	✓	✓

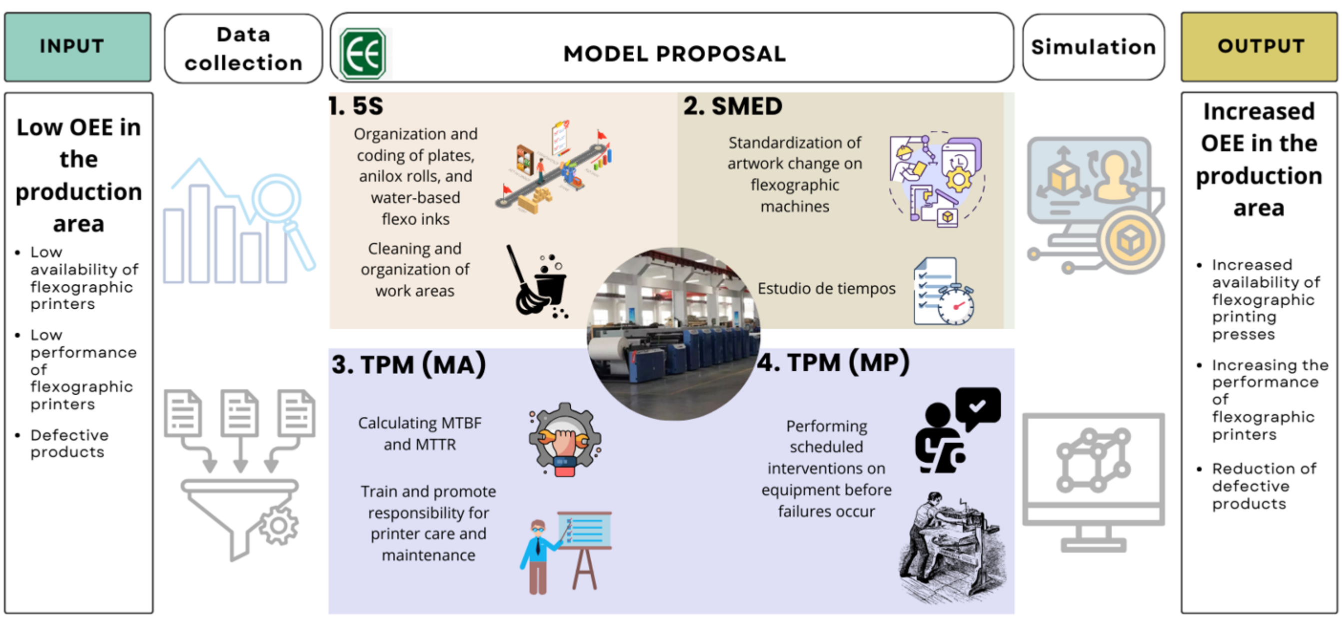

Fig. 1 Proposed innovative model

D. Model components

Component 1: Analysis of the current situation

This component focuses on identifying problems affecting operational efficiency. By analyzing OEE indicators, deficiencies in availability, performance, and quality are detected. Tools such as value stream mapping (VSM) and the "5 Whys" technique help identify bottlenecks and their root causes. With this information, Pareto charts are developed to prioritize problems and define corrective actions.

Component 2: Intervention

The intervention includes the implementation of 5S, SMED, and TPM methodologies. The 5S methodology improves the organization of the work environment, establishing standards for cleanliness and order. SMED optimizes machine setup times by converting internal activities into external ones and standardizing procedures. Finally, TPM ensures the sustainability of improvements through autonomous and planned maintenance strategies, staff training, and monitoring of key indicators such as MTBF and MTTR.

Component 3: Validation

This component evaluates the effectiveness of the implemented improvements through simulations. Key indicators are compared before and after the intervention, allowing for verification of increases in OEE and adjustments to the model if necessary. **Figure 2** illustrates the flow of the validation process.

E. Model indicators

The model uses OEE as its primary indicator, broken down into three sub-indicators: availability, performance, and quality. These are calculated using the following formulas:

$$OEE(\%) = Disponibilidad \times rendimiento \times calidad \quad (1)$$

This indicator provides an overview of the equipment's performance in terms of efficient and defect-free production.

Availability is the indicator that evaluates the percentage of time the equipment is operational relative to the total planned production time. Initially, this indicator was 82.44% and is calculated as follows:

$$Disponibilidad = \frac{\text{Tiempo Operativo} \times 100}{\text{Tiempo Producción Planificado}} \quad (2)$$

This metric helps identify losses due to downtime, such as unplanned shutdowns and extended maintenance.

Efficiency also measures the efficiency of machinery by comparing actual production speed with the ideal. Initially, this indicator was estimated at 81.5% and is defined by the following formula:

$$Rendimiento(\%) = \frac{\text{Producción Real}}{\text{Producción Ideal}} \times 100 \quad (3)$$

This indicator identifies losses due to low operating speeds or minor interruptions.

Finally, quality reflects the percentage of products that meet established standards in relation to the total produced. Initially, this indicator had a value of 89.17% and is calculated as follows:

$$Calidad = \frac{\text{Unidades Aceptables}}{\text{Unidades Totales Producidas}} \times 100 \quad (4)$$

This indicator assesses the impact of defects and reprocessing on the overall product.

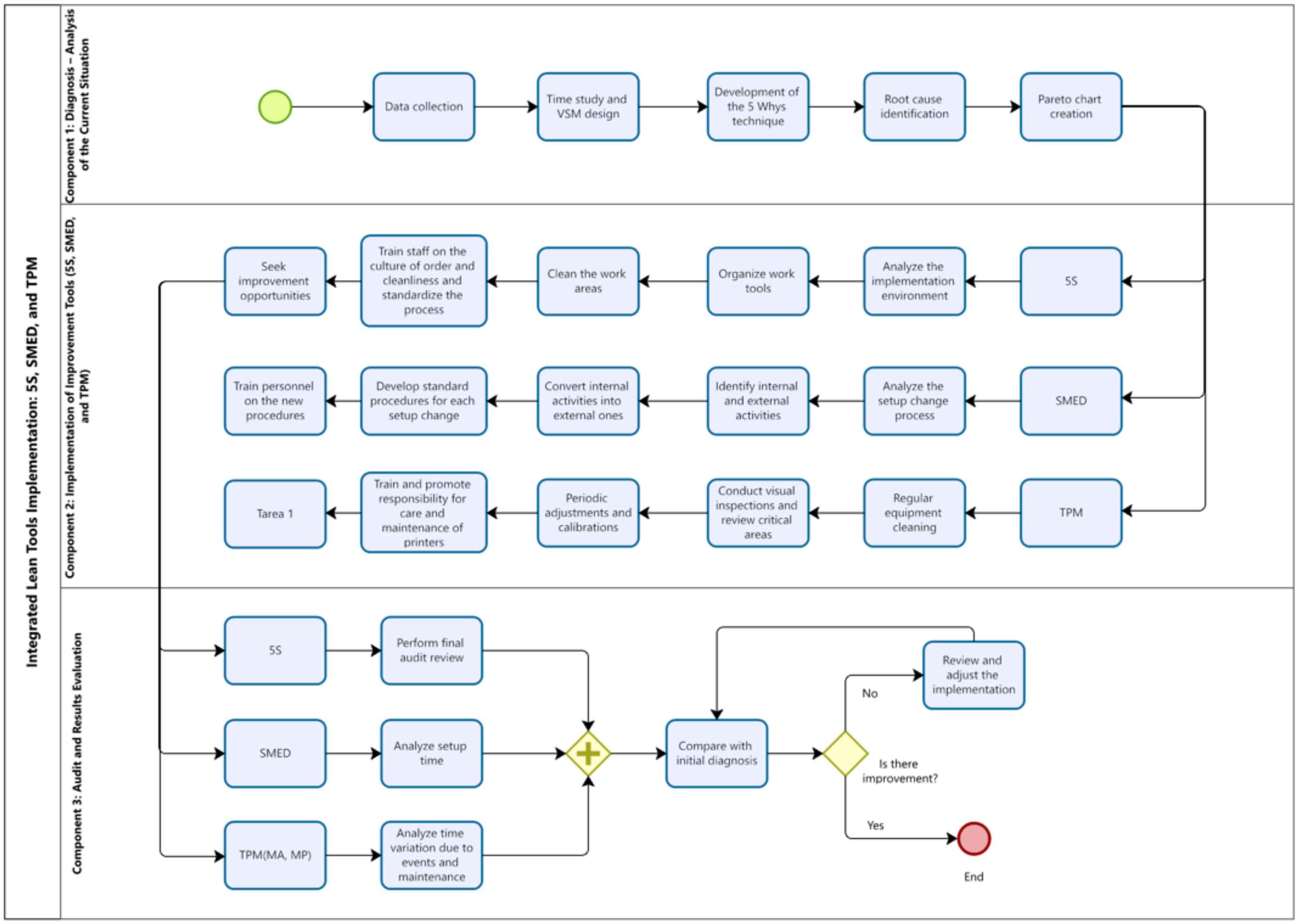

Fig. 2. Flow of the proposed method

IV. Results

A. Description of the scenario

The case study was conducted at the Case St. flexographic printing plant. Before applying the improvement model, the evaluated printer had an OEE of 59.91%, considerably lower than the international standard of 85%. This low efficiency generated annual economic losses of approximately 190,046 soles, equivalent to 8.39% of annual sales. The problem tree summarizing the main operational causes detected is presented in **Figure 3**, highlighting the lack of standardized artwork changeovers, the high frequency of breakdowns, and poor cleaning control.

B. Initial diagnosis

Analysis of historical data from 2023 showed an average availability of 82.44%, a yield of 81.50%, and a quality of 89.17%, resulting in an overall OEE of 59.91%. Furthermore, setup times averaged 241 minutes, and the defective product rate reached 10.83%. These deficiencies were primarily attributed to a lack of effective autonomous maintenance, the absence of standardized protocols, and inadequate control of critical operating factors.

C. Design and validation results

Component 1: Validation method

The improvement proposal was validated through pilot tests specific to each methodology (5S, SMED, and TPM), evaluating the results obtained in isolation to identify opportunities for adjustment. The integrated model was subsequently validated through simulation using Arena software. Detailed measurements of setup times, unplanned downtime incidences, and defect rates were taken before and after the implementation of the improvements, allowing for an objective comparison of the results.

Component 2: Simulation of the model in the Software Arena

The simulation modelled a production volume of 379 kg of printed paper, representative of a day's operation, and calculated for a 95% confidence level with a 5% margin of error. The model incorporated optimized setup times, planned and unplanned downtimes using MTBF and MTTR distributions, and a quality control module that assigned average inspection times of 5 to 10 minutes per batch. The initial configuration of the modelled system is presented in **Figure 4**, while the improvements implemented in the production flow are reflected in **Figure 5**.

Component 3: Simulation results

The "As-Is" scenario simulation reported an average setup time of 241 minutes (95% CI: 231–250 minutes), a machine utilization of 0.81510 (95% CI: 0.80815–0.82205), and an average cycle time of 3,444.4 minutes (95% CI: 3,404.5–3,484.3). These results are reasonably consistent with historical plant data, although some differences suggest inherent model limitations.

In the improved (To-Be) scenario, after the implementation of 5S, SMED and TPM tools, the average setup time was reduced to 171 minutes (95% CI between 164 and 179), utilization increased to 0.872 (95% CI between 0.866 and 0.878) and cycle time was reduced to 3,313.8 minutes (95% CI between 3,271.7 and 3,354.2). The projected OEE in this improved scenario reached 70.84%, which represents an improvement of 10.93%. **Table II** summarizes the main comparative indicators between the initial scenario and the improved scenario.

Despite the favourable results, the simulation has limitations compared to actual plant behaviour. First, the failure and repair distributions used do not fully capture the variability observed in historical maintenance records, representing average conditions that omit atypical failures. Second, the simulation did not model unplanned events, such as shutdowns due to lack of supplies, last-minute manual adjustments, or quality issues, all of which significantly impact actual operations. Finally, the Arena software's workflow logic automates resource allocation, eliminating manual bottlenecks and delays common in plant environments.

These differences suggest that simulated results should be considered indicative approximations rather than exact predictions. For greater accuracy, it is recommended to periodically calibrate model parameters, incorporate random events into the simulation, and validate the results against updated field data.

Table II
Results of the Validation process

Indicators	**Original Model**	**Proposed Model**	**Improvement**
OEE	59.91%	71.84%	18.24%
Availability	82.44%	87.72%	6.22%
Product defect rate	10.83%	7.77%	28.26%
Setup Time	241 min	171 min	29.05%
MTBF	5,413 hours/failure	9,743 hours/failure	80.04%
MTTR	2.6 hours/failure	1.9 hours/failure	26.51%
Performance	81.50%	87.72%	7.63%

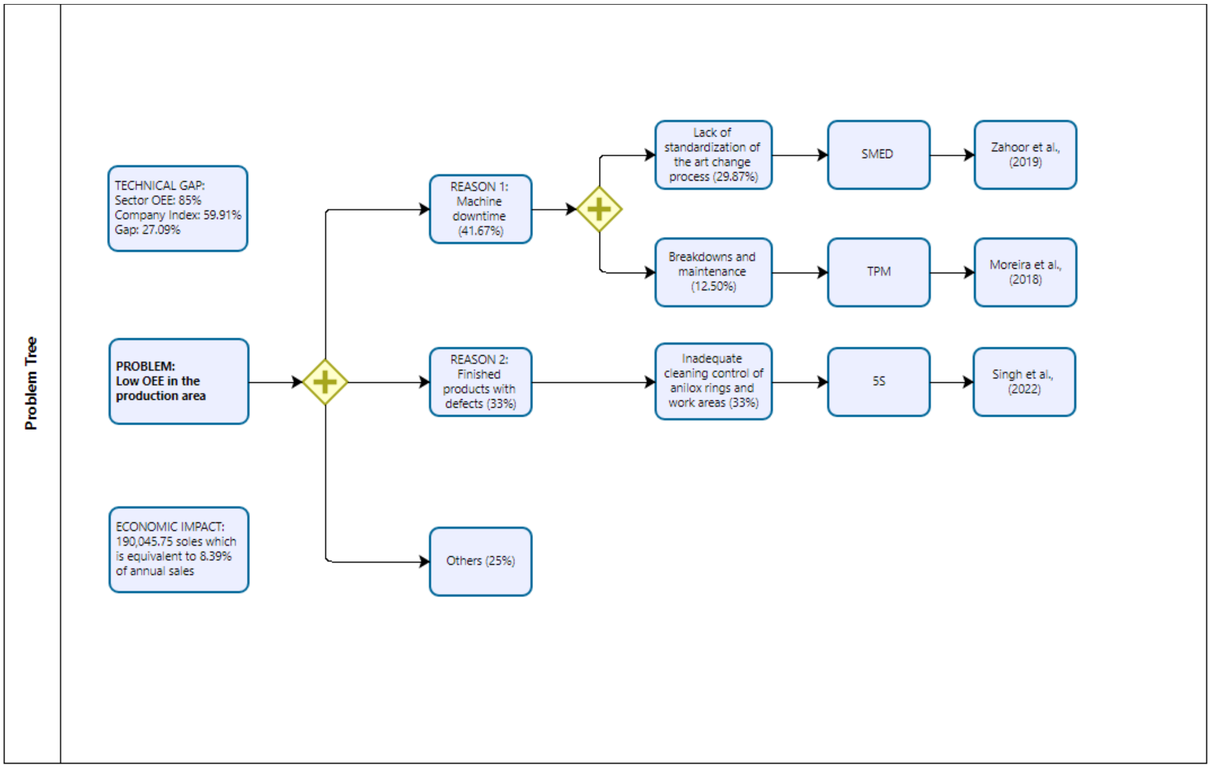

Fig. 3 Problem tree

Fig. 4 Representation of the system in Arena Simulator V16.2 software before the upgrade

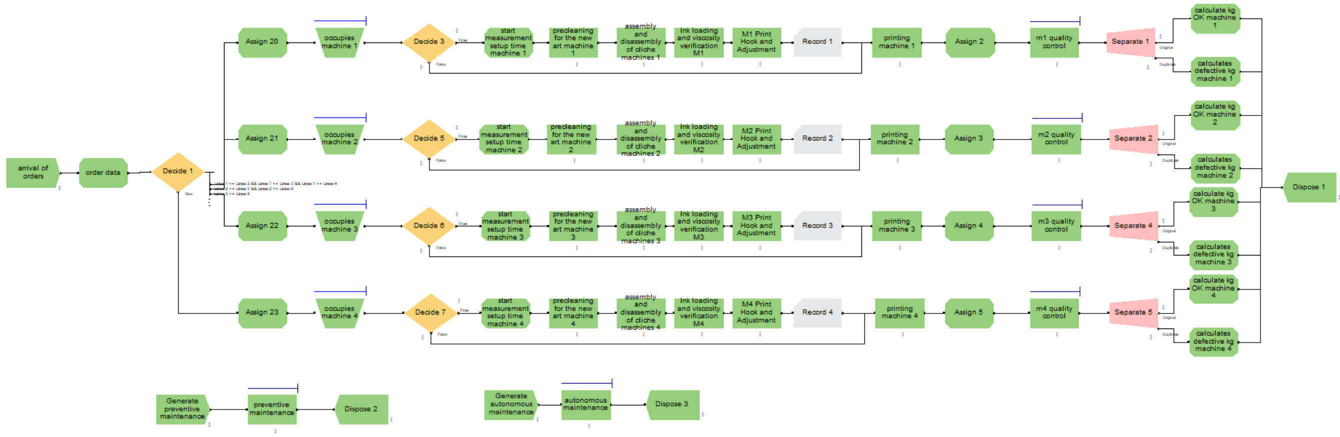

Fig. 5 Representation of the system in Arena Simulator V16.2 software after the upgrade

Component 4 Economic Validation

The initial investment required was 24,803 soles, distributed between tangible and intangible assets needed to implement the improvement model. This initial investment made it possible to address the main inefficiencies identified in the production process.

The analysis yielded a Financial Net Present Value (FNPV) of 155,032.54 PEN, confirming that the project will generate significant economic benefits that exceed the costs incurred. The financial Internal Rate of Return (IRR) was 284%, highlighting the high profitability of the implemented model. Furthermore, the Benefit/Cost (B/C) ratio reached 7.25, demonstrating a return on each sol invested that is substantially higher than the initial investment.

On the other hand, the financial payback period was estimated at just 0.69 years, indicating that the return on investment will be achieved in less than six months from the model's implementation. These results reflect not only the project's operational efficiency but also its ability to generate sustainable economic benefits over time. The economic indicators obtained are detailed in **Table III**.

TABLE III
RESULTS OF ECONOMIC INDICATORS

Indicators	Results
NPV	155,032.54 PEN
IRR	284%
B/CE (ROI E)	7.25
PAYBACK	0.69

V. DISCUSSION

The economic evaluation of the project demonstrated its long-term financial viability and profitability.

The results show significant improvements in operational and economic performance following the integration of 5S, SMED and TPM methodologies in the flexographic industry. The OEE increased from 59.91% to 71.91%, which represents an increase of 20.03% [1], [2] and brings the company closer to international standards of operational efficiency [8].

At the component level, availability increased by 6.22% thanks to the optimization of line changeover times using SMED [6]. Quality improved, with defective products reduced to 7.77% after the application of TPM [1]. Furthermore, yield increased from 81.5% to 87.72%, corroborating the effectiveness of the proposed model [6].

From the economic point of view, the financial analysis showed a NPV of 155,033 PEN, an IRR of 284% and a recovery period of 0.69 years, exceeding the values reported in similar studies in manufacturing [4].

However, the study has two main limitations. First, the follow-up is limited to three months, so more extensive longitudinal data are needed to validate the persistence of improvements. Second, variability in staff and management commitment may affect the 5S discipline [17].

To mitigate these barriers, it is recommended to implement ongoing training programs, establish real-time performance monitoring systems, and develop internal awareness campaigns that reinforce the importance of audits and organizational commitment.

As future lines of research, we propose integrating predictive analysis based on artificial intelligence to anticipate failures and optimize maintenance, as well as assessing the environmental impact of the improvements implemented in terms of waste generation and energy consumption.

Section VI presents the general conclusions of the study.

VI. Conclusions

The objective of this research was to develop and implement a comprehensive model based on 5S, SMED, and TPM methodologies to improve the OEE of flexographic printing presses in a company in the graphic industry. The results confirm that the model fulfills its purpose: OEE increased from 59.91% to 71.91%, availability increased by 6.22%, the defect rate decreased to 8.27%, and yield increased from 81.5% to 87.72%. From an economic perspective, the project demonstrated its viability with a Net Present Value of 157,576 PEN, an IRR of 284%, and a payback period of 0.69 years.

These findings demonstrate that the model not only achieves the operational and financial objectives set but also offers a replicable and adaptable framework for other industrial environments with similar characteristics. Reflection on the objective shows that sequentially integrating 5S, SMED, and TPM provides not only quantitative improvements (OEE, availability, quality, performance) but also a drive toward a culture of continuous improvement.

However, to ensure the sustainability of these benefits, it is essential to address two challenges: operational staff resistance to change and supervisory commitment to periodic audits. It is recommended to implement change management strategies (continuous training programs, internal communication) and real-time monitoring systems that reinforce 5S discipline and the effectiveness of SMED and TPM on a sustained basis.

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