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Improving the efficiency of the flooring production process in a timber company through the application of TPM and SMED

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Abstract: The Peruvian wood industry faces operational inefficiencies that limit its competitiveness despite the growth of the global market. Although the country possesses abundant forest resources, low productive efficiency and high levels of informality have led to a 15.8% decrease in the sector's international market participation between 2023 and 2024. This issue is reflected in a Peruvian company that produce solid wood flooring, where the machining stage concentrates unplanned stoppages, reducing equipment efficiency and generating economic losses and delays in order delivery. To address these limitations, the study applied Total Productive Maintenance (TPM), through its autonomous and planned maintenance pillars, together with SMED (Single Minute Exchange of Die), in order to reduce mechanical failures and setup times. Validation was carried out through the simulation of the As-Is and To-Be scenarios in Arena, using indicators such as efficiency, availability, setup time, and MTBF. The results show that the integration of TPM and SMED can be effectively applied to the solid wood flooring production process, a sector where no prior documented applications of these methodologies have been identified. The simulation showed improvements of 6.6% in efficiency, 15.0% in availability, a 34.9% reduction in setup time, and a 50.8% increase in MTBF. Overall, the combined TPM–SMED approach is an effective strategy for optimizing operational performance and strengthening the competitiveness of the wood manufacturing sector.

Palabras clave: TPM; SMED; efficiency; machine availability.

I. Introduction

A. Background

The global wood flooring market shows sustained growth, with a compound annual rate of 5.78% between 2024 and 2029, driven by the demand for sustainable and natural products for construction and interior design [1].

However, this growth is not reflected in Peru. Despite Peru's extensive forest wealth, its share in the international market dropped by 15.8% between 2023 and 2024. [2]. This situation is mainly due to the high level of informality within the sector and persistent operational inefficiencies that directly affect productive performance. Reports indicate that Peruvian wood manufacturers face challenges such as low utilization of installed capacity, limited technological development, frequent unplanned stoppages, and inadequate maintenance practices, all of which reduce the consistency and reliability of production processes. As a result, the sector struggles to reach productivity levels comparable to more competitive industries in countries such as Chile and Brazil [3].

B. State of Art

A review of studies addressing low efficiency in industrial processes shows that the most widely used improvement tools are TPM, SMED, Standard Work, and 5S. These methodologies have been applied in metalworking, plastics, automotive, and textile industries, consistently demonstrating increases in operational efficiency, reductions in non-productive time, and improvements in overall productivity [4].

Regarding TPM, several studies report improvements in efficiency by reducing recurring failures, lowering material-related losses, and improving maintenance activities. For example, TPM has been shown to reduce mechanical issues and material jams, decreasing losses by up to 18% and increasing operating income by 18.5% in automotive production lines [5]. Other research shows that structured maintenance plans can reduce downtime caused by breakdowns by 38% [6]. When combined with training and preventive maintenance, TPM also helps improve cycle times and standardize work practices, strengthening preventive culture in plants [7]. Overall, TPM contributes to more stable and efficient operations.

Similarly, research on SMED shows significant reductions in setup times, which directly impact overall efficiency. For instance, in a plastic-cutting line, SMED reduced setup time by 43% by reorganizing which tasks are done while the machine is stopped, and which can be done beforehand [8]. In plastic injection processes, combining SMED with standardization and operator training reduced mold-change times by 46.3% [9]. Other studies show improvements when SMED is applied together with Kaizen and production scheduling, helping reduce unnecessary stoppages and improving coordination between batches [10]. The literature highlights that SMED works best when setup activities are clearly analyzed, tasks are categorized correctly, and operators actively participate [11].

Additional methods such as Standard Work and 5S also show positive results by increasing task repeatability, reducing human variability, and improving workplace organization. Standard Work helps improve cycle times by establishing clear task sequences that reduce errors [4]. Likewise, applying 5S along with basic maintenance activities has led to increases of 10% in productivity and 23.8% in efficiency, as well as reductions of 32.04% in setup time across different industries [12]. Combining SMED, 5S, and preventive maintenance has also helped reduce production costs and improve workflow.

However, after reviewing the existing literature, it becomes evident that the combined application of these methodologies in hardwood flooring manufacturing companies particularly in low-automation contexts such as the Peruvian wood industry, remains limited. This gap underscores the relevance of the present study and highlights the opportunity to apply TPM and SMED to improve efficiency in this type of production process.

C. *Case of Study*

The case study focuses on the production process of a Peruvian company dedicated to the manufacturing and export of solid wood flooring. The production line consists of three sequential stages: pre-dimensioning, optimization, and machining. This research centers on the machining stage where the moulder machine is located. This equipment is the most critical component of the line, accounting for 54.9% of unplanned stoppages and representing the main source of performance losses and low operational efficiency.

The main problem identified in the company is low production efficiency, which limits its ability to meet delivery deadlines and maintain stable production levels. This issue is mainly explained by low machine availability, which is primarily caused by mechanical failures, followed by configuration problems and material jamming, and finally by electrical failures, as shown in Fig. 1.

To address these issues, this study proposes the application of Total Productive Maintenance (TPM) and Single-Minute Exchange of Die (SMED) to reduce non-productive time, improve machine availability, and enhance the performance of the machining stage.

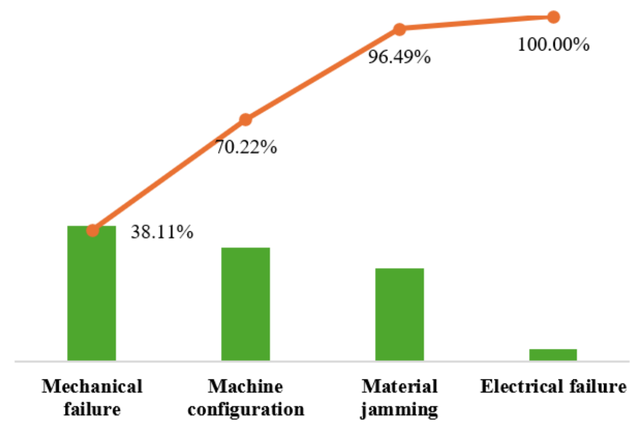

Fig. 1. Pareto Diagram of Production Downtime Causes

D. *Objectives*

The main objective of this study is to increase the efficiency of the solid wood flooring production process, targeting an improvement up to 85%.

The specific objectives are:

- Increase the Mean Time Between Failures by 35%.
- Reduce setup times in critical operations by 32%.
- Increase machine operational availability by 35%.

II. Methodology

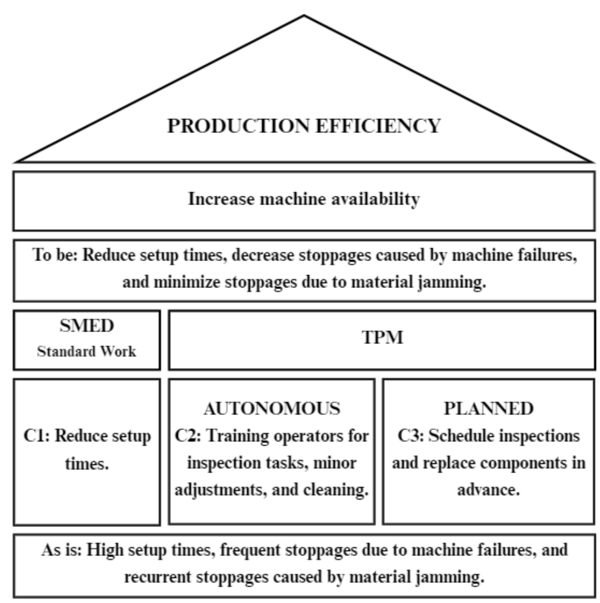

Fig. 2. Conceptual model

As shown in Fig. 2, the conceptual model is designed as a system in which increasing machine availability acts as the main driver for improving production efficiency in the solid wood flooring line. The model addresses three primary sources of downtime: long setup times, stoppages caused by machine failures, and stoppages due to material jamming.

Previous studies [6], [8] show that these tools help reduce setup times and improve availability and efficiency. In addition, Standard Work supports the model by standardizing key activities to ensure they are done safely, efficiently, and in the same way every time.

The model integrates the Autonomous Maintenance and Planned Maintenance pillars of TPM with SMED, creating a complementary system where each methodology reinforces the others to reduce unplanned stoppages and stabilize machine performance.

To measure the impact of the proposed model, four performance indicators were selected:

- $\text{Efficiency}(\%) = \frac{\text{Standard Output}}{\text{Actual Output}} \text{ x } 100$
- $\text{Availability}(\%) = \frac{\text{Planned Production Time} - \text{Downtime}}{\text{Planned Production Time}} \text{ x } 100$
- $\text{Setup Time (min)} = \frac{\text{Total Setup Time}}{\text{Number of Setup}}$
- $\text{MTBF (hours)} = \frac{\text{Total Operating Time}}{\text{Number of Failures}}$

These indicators and their respective baseline values (As-Is), as well as projected improvements (To-Be), are presented in Table I.

TABLE I
Indicator

Indicator	Component	As-Is	To-Be
Efficiency (%)	C1, C2, C3	70.50	85 [13]
Availability (%)	C1, C2, C3	57.30	90 [13]
Setup Time (min)	C1	229	155.72 [12]
MTBF (hours)	C2, C3	299	403.65 [12]

A. Component 1: Implementation of SMED

Stage 1: Analysis of Current Setup Activities.

In this stage, all activities performed during the machine setup process were identified and recorded. Each task was analyzed considering its duration, purpose, and the resources involved. This analysis allowed the identification of inefficiencies and established the baseline for the improvement proposal.

Stage 2: Classification and Conversion of Activities.

Activities were first classified as internal (those that can only be performed when the machine is stopped) and external (those that can be carried out while the machine is operating), following the methodology described in [8]. Based on this classification, the feasibility of converting certain internal activities into external ones was assessed through procedural or technical adjustments, such as the prior preparation of tools and materials. This integrated process aimed to reduce non-productive time, optimize setup efficiency, and increase machine availability.

Stage 3: Reduction of Internal Activity Time.

For internal activities that could not be externalized, optimization opportunities were analyzed through the standardization of procedures, simplification of movements, and the use of visual aids. The Standard Work approach was applied to reduce variability and ensure repeatability in setup operations.

The results of the activity analysis and classification before and after the SMED implementation are presented in Table II, showing a significant reduction in internal activity time and an increase in external activities.

TABLE II
Classification of Activities

Indicator	As-Is	To-Be	Variation
Internal Activities (units)	20	14	-30%
Setup Time (min)	229	149	-80 min (-34.93%)

TPM Implementation

To implement autonomous and preventive maintenance in the process, awareness and commitment were promoted across all levels of the organization by communicating the objectives and benefits of TPM and emphasizing its positive impact on operational efficiency and quality, as reported in [14] and [15]. Three teams were formed: one composed of supervisors and company management, a second made up of maintenance personnel, and a third consisting of machine operators. The first two teams oversaw the implementation, set objectives, and monitored progress.

A detailed and comprehensive assessment of the current state of the machines involved in the wood flooring production cycle was carried out to identify critical equipment for performance evaluation and analyze existing problems.

Based on this assessment, action plans were created to address the identified issues and achieve the TPM objectives. These plans included specific activities, the person responsible for each activity, deadlines and the necessary resources.

B. Component 2: Implementation of Autonomous Maintenance

The Autonomous Maintenance initiative aims to increase operator involvement in machinery maintenance by training them to carry out basic inspections, cleaning and minor adjustments to prevent breakdowns and unplanned downtime. The initiative aims to reduce unproductive time associated with material jams and minor component wear, which accounted for 26.28% of total downtime during the moulding stage.

Stage 1: Inspection, Initial Cleaning, and Standardization of Cleaning.

In this stage, the moulding machine is inspected and cleaned as a starting point to ensure proper operation and to identify actions that operators can perform to improve performance. The process includes calibrating, aligning, and verifying critical components such as shafts, bearings, blades, and cutter heads and defining which tasks must be performed before and after operation. A standardized cleaning procedure is established, along with pre- and post-operation maintenance log sheets, as shown in Table III, titled "Separation and Duration of Pre- and Post-Use Maintenance Activities of the Machine." These instruments are designed to document daily routines and ensure consistent execution across shifts and among all operators.

Likewise, the times reported in Table III may initially appear high and somewhat discouraging; however, prior to the implementation of these specific activities, operators conducted maintenance in a highly disorganized manner, overlooking essential inspections and allocating only 30 minutes of the workday to this task. Although the structured maintenance now requires a total of 2 hours and 50 minutes, this investment is fully justified, as it has substantially reduced unplanned stops resulting from machine failures and material jamming associated with inadequate cleaning, calibration, blade replacement, among other factors.

TABLE III

Separation and duration of pre- and post-use maintenance activities of the machine

Activities Pre-operation	Number of activities	Duration time
Activity 1: Equipment Inspection	5	30 min
Activity 2: Component Cleaning	3	27 min
Activity 3: Machine Calibration	4	32 min
Activity 4: Electrical Component Maintenance	4	28 min
Total time:	1 hour and 57 min	
Activities Post-operation	Number of activities	Duration time
Activity 1: Equipment Inspection	2	8 min
Activity 2: Component Cleaning	3	24 min
Activity 3: Electrical Component Maintenance	3	21 min
Total time:	53 min	

Stage 2: Operator Training

A training program is provided to operators focusing on the proper use of maintenance forms, early detection of anomalies, and incident reporting through standardized records.

Stage 3: Monitoring Results

A weekly monitoring system is established, along with biweekly feedback meetings between the production manager, maintenance manager, and selected operators to evaluate results, verify maintenance frequency, and adjust tasks based on recorded information.

C. Component 3: Implementation of Planned Maintenance

The objective of planned maintenance is to anticipate mechanical and electrical failures in the moulding machine by systematically scheduling inspections and replacing critical components in a timely manner. This component aims to reduce, and eventually eliminate, unplanned downtime, which previously accounted for 41.6% of unproductive time. This will increase the machine's operational availability.

Stage 1: Development of the Strategic Master Plan and Collection of Equipment Information

This stage consists of developing a strategic master plan that defines the roles, responsibilities, and technical resources required to carry out preventive maintenance. Additionally, this stage includes collecting and classifying historical data on failures, spare parts consumption, and repair times using standardized equipment monitoring and recording formats.

Stage 2: Development and Scheduling of Preventive Maintenance

In this stage, a preventive maintenance plan is developed for both mechanical and electrical systems, covering activities such as belt replacement, gearbox inspection, drive shaft lubrication, blade sharpening, and electrical and safety system checks. Additionally, a maintenance schedule is established, planning interventions during weekends to avoid affecting production while complying with Peruvian overtime regulations.

Stage 3: Information Management.

In the final stage, an information management system based on performance indicators particularly MTBF (Mean Time Between Failures) is established to evaluate failure frequency and adjust the scheduling of maintenance interventions. Similar to autonomous maintenance, this stage includes analysis and feedback meetings to review planned maintenance results and modify intervention intervals when necessary.

Finally, key performance indicators (KPIs) were established to measure the performance of these two TPM pillars. The indicators proposed by [16] were used as a reference, and the results were monitored and evaluated periodically to identify areas for improvement.

III. Results

A. Validation

The validation of the proposed improvement model was carried out through a simulation developed in Arena Simulation Software. The objective was to compare the performance of the current (As-Is) scenario with the improved (To-Be) scenario. The latter includes the application of the SMED methodology along with the Autonomous Maintenance and Planned Maintenance pillars of TPM. The improvements implemented include the conversion of internal activities to external ones, the reduction of machine stoppage frequency, and the decrease in maintenance time associated with these events.

Fig. 3 presents the model developed in Arena, which replicates the machining stage of the production line, as well as the machine setup process, the failure events that occur during operation, and the time required for their repair.

The information used to design the model was obtained through time measurements of the setup process activities and from incident reports provided by the company. To ensure the reliability of the results, the model was executed with 30 replications at a 95% confidence level. The performance indicators were recorded using Record modules and analyzed through simulation output reports.

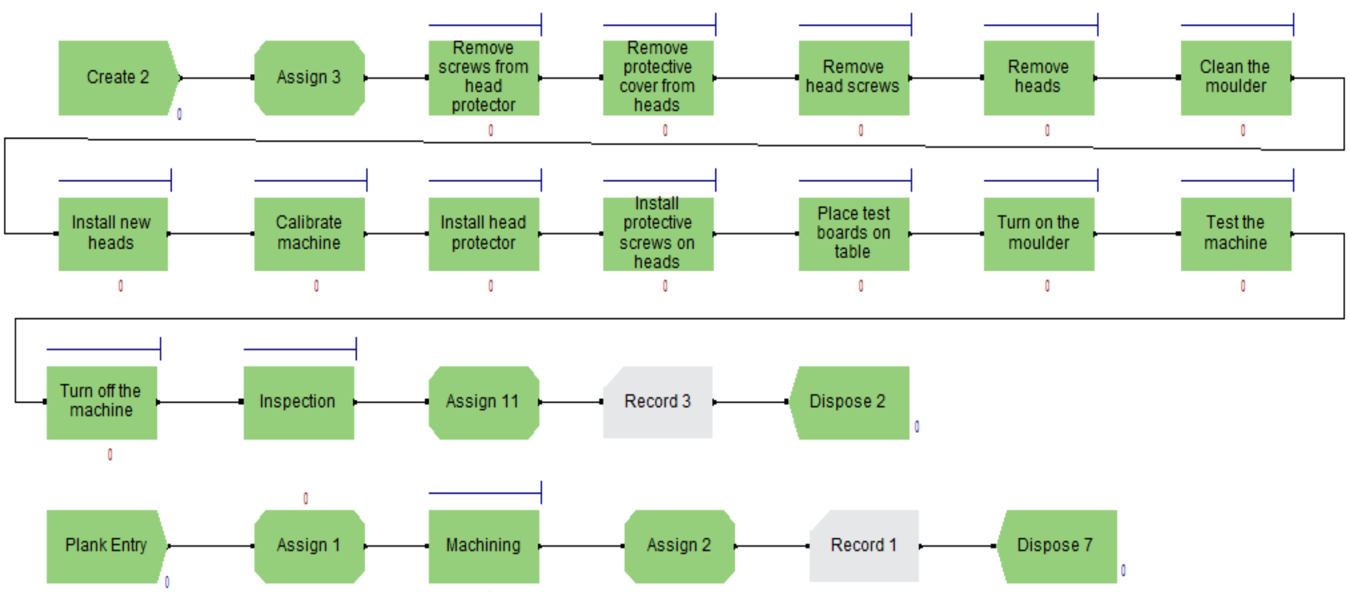

Fig. 3. Simulation

B. Simulation results

TABLE IV presents the results obtained in the To-Be scenario after the implementation of the improvement model. The evaluated indicators include efficiency, availability, setup time, and MTBF, along with their statistical characteristics such as average value, standard deviation, confidence interval half-width, and observed minimum and maximum values.

TABLE IV
Output Analyzer

Indicator	Avg.	Std. Dev.	95% CI Half-Width	Min	Max
Efficiency (%)	77.1	0.12	0.04	76.8	77.3
Availability (%)	72.3	0.33	0.12	71.6	72.9
Setup (min)	149	0.20	0.07	148	149
MTBF (hours)	451	28.20	10.50	398	515

The following section presents the results obtained for each indicator evaluated in the simulation, comparing the As-Is and To-Be scenarios.

Efficiency increased from 70.5% (As-Is) to 77.1% (Achieved), as shown in Fig. 4. Although the To-Be scenario projected an efficiency of 85%, the achieved value still represents a significant improvement over the baseline. This result is mainly explained by the reduction in unplanned stoppages and the optimization of setup activities, which increased the proportion of productive operating time.

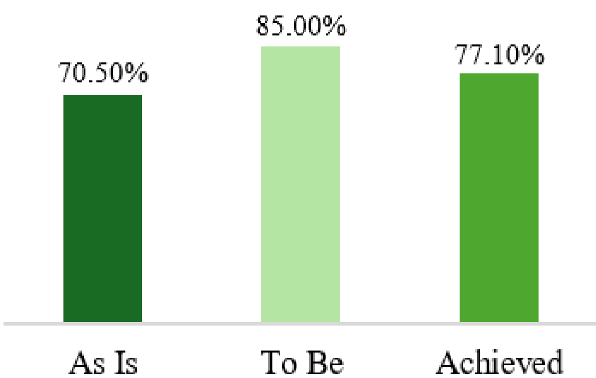

Fig. 4. Efficiency

Availability improved from 57.3% (As-Is) to 72.3% (Achieved), as presented in Fig. 5. While the To-Be projection estimated an availability of 90%, the achieved performance reflects a considerable reduction in downtime. This improvement is primarily due to fewer stoppages, enhanced cleaning and lubrication routines, and more efficient corrective and preventive maintenance practices.

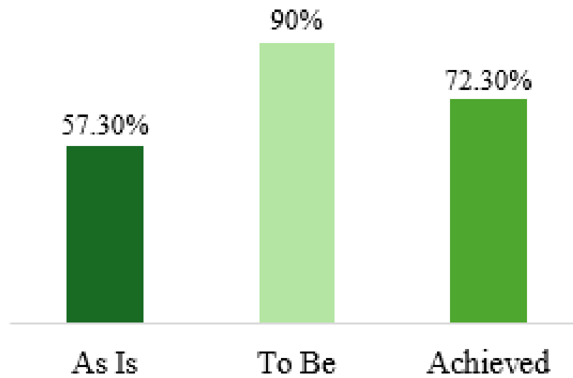

Fig. 5. Availability

Setup time decreased from 229 minutes (As-Is) to 149 minutes (Achieved), as shown in Fig. 6. This result closely aligns with the To-Be projection of 156 minutes and validates the impact of SMED based improvements, particularly the separation of internal and external activities, the standardization of changeover tasks, and the elimination of unnecessary preparation steps.

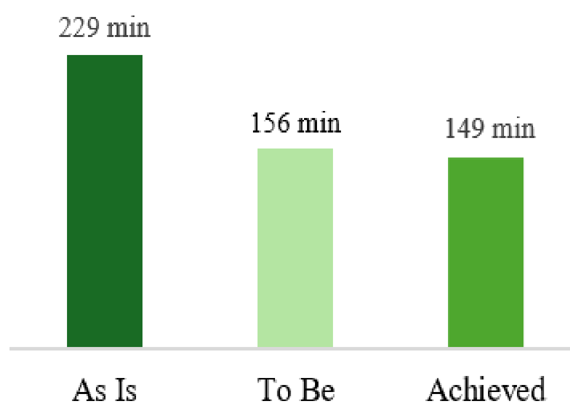

Fig. 6. Setup Time

MTBF increased from 299 minutes (As-Is) to 451 minutes (Achieved), as illustrated in Fig. 7. This value exceeds the To-Be projection of 404 minutes, indicating improved equipment reliability. The increase in MTBF is attributed to more consistent maintenance routines, better operator involvement through Autonomous Maintenance, and a reduction in material jamming events.

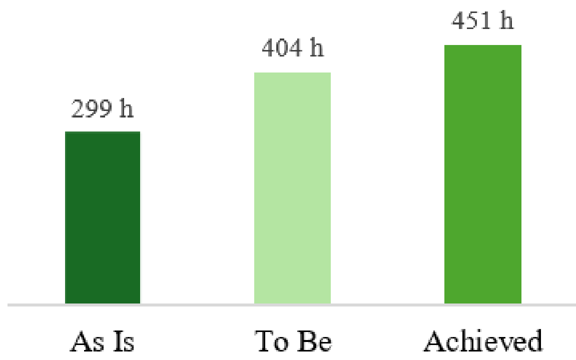

Fig. 7. MTBF

IV. Discussion

The implementation of TPM and SMED in the solid wood flooring production line generated significant improvements in the simulated system. Setup time was reduced by 34.9%, MTBF increased by 50.8%, and availability and efficiency improved by 15.0% and 6.6%, respectively, compared to the As-Is scenario. These results are consistent with the literature reviewed in this study. Regarding setup time, prior studies have reported significant reductions through the application of SMED, with values ranging from 43% [8] to 32.04% [12]. The 34.9% reduction obtained in this study falls within this range, demonstrating the effectiveness of the proposed setup redesign. The MTBF increased from 229 h to 451 h, representing a 50.8% improvement. This result is consistent with previous studies in which the application of TPM significantly enhanced system reliability, with reported increases from 55.6 h to 286 h [5] and from 50.86 h to 237.65 h [13].

However, in terms of availability and efficiency, the results differ from those reported in previous studies. Regarding availability, prior research has reported increases reaching values between 80% and 96.88% through the application of planned and predictive maintenance [7]. In comparison, this study achieved a 15.0% improvement in availability. Similarly, efficiency increased by 6.6%, although this value is lower than those reported in the literature, such as improvements from 56% to 85% [16] and gains of 23.8% in metalworking environments [12]. These differences suggest that the impact of TPM and SMED is strongly influenced by the specific operational conditions of each system.

This gap can be explained by the statistical variability inherent to the modeled process, including the probabilistic distribution of operation times, the randomness of material jamming events, and the persistence of machine failures even after the implementation of improvements. These factors limit the magnitude of achievable improvements, as also observed in systems with high variability where model fluctuations prevent reaching target values [7], [10]. In this context, a limitation of the study is the absence of a sensitivity analysis to evaluate the effect of variations in key parameters, such as failure rates and setup times, which could provide a deeper understanding of the model's robustness under different conditions.

Finally, the results highlight the potential applicability of the model in smaller wood-manufacturing companies, where reducing non-productive time can have a significant impact. Moreover, the methodology could be extended to other wood-processing lines, such as multilayer flooring, mouldings, decking, or structural components, which face similar challenges related to unplanned stoppages and raw material variability. Future research should incorporate sensitivity analysis and alternative scenarios to strengthen the robustness and generalizability of the model across different industrial contexts.

V. Conclusion

The proposed model improved process efficiency, increasing it from 70.5% to 77.1%. However, it did not reach the target of 85%, which suggests that additional improvements or a longer implementation period may be required.

The reduction in setup time was successfully achieved, decreasing setup duration by 34.9%, which aligns with the objective of reducing setup operations by 32%.

The model exceeded expectations in reliability, increasing MTBF by 51%, surpassing the original objective of a 35% increase, confirming significant improvement in equipment failure management.

Machine availability improved but did not reach the target, increasing from 57.3% to 72.3%, which represents progress but falls short of the expected 35% increase required to reach 85%.

Overall, this research contributes to the body of knowledge in industrial maintenance by demonstrating that TPM and SMED can be effectively adapted to the conditions of the Peruvian wood manufacturing sector, characterized by low automation, operational informality, and a lack of standardized maintenance practices. The results highlight the potential of these methodologies not only for flooring production but also for other wood-processing lines, positioning this study as a solid foundation for future applications and research within the sector.

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