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Application of SLP and TPM to Increase the Complete Order Rate at an MSE

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Abstract

The research aimed to increase the Complete Order Rate (COR) in a micro and small enterprise (MSE) dedicated to manufacturing cardboard binders. The company presented a low COR of 76.21%, resulting in an estimated economic impact equivalent to 5.1% of revenue from these products. The three main root causes identified were delays during the production process, obstructions caused by materials and pallets, and the absence of a formal maintenance system. To address these issues, Systematic Layout Planning (SLP) was proposed for the plant, while Total Productive Maintenance (TPM) was implemented through a pilot test exclusively on the riveting machine. The Arena simulation results showed a 20.98% increase in the Complete Order Rate, together with similar improvements in Overall Equipment Effectiveness (OEE) and in partial machinery productivity. The TPM pilot test provided the maintenance-time data used to parameterize the proposed simulation scenario.

Keywords: Discrete Event Simulation, Complete orders rate, Manufacturing industry, MSE, OEE, SLP, TPM

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1. Introduction

The manufacturing sector's Gross Domestic Product (GDP) grew by 5.5% in January 2025 compared with January 2024, driven by the positive performance of non-primary manufacturing (+1.7%)., the recovery of domestic demand, and the increase in industrial exports. Within this subsector, paper and cardboard manufacturing companies showed an increase of 26% [1].

In a Regional Report, the International Labour Organization (OIT) states that "the average hourly productivity in Latin America was USD 22.1." In Peru, an approximate value of USD 15 per hour worked was recorded, while in countries such as Mexico, Argentina, Chile, and Uruguay, productivity reached USD 30 per hour worked [2].

The case study corresponds to a micro and small manufacturing enterprise (MSE) located in Lima, dedicated to the production and distribution of various office supplies. Cardboard binders are its main product and represent approximately 34.43% of total production. This production line is composed of 10 activities, ranging from cutting the paper to pallet stacking, and operates with 9 machines distributed throughout the process.

The analysis of the company's situation made it possible to identify that its main problem is the low rate of complete

orders (COR), which amounts to 76.21%. The COR is calculated as:

$$COR = \frac{Complete\ orders}{Total\ orde\ rsreceived} \times 100$$

In comparison, a Peruvian printing company reports only 98.49% [3].

This gap generates an opportunity cost equivalent to S/ 82,005.60 in lost revenue, representing 5.1% of cardboard binder sales. Additionally, the company's Overall Equipment Effectiveness (OEE) is 74.29%, which is below the target value of 85% [4]. This situation compromises operational performance and limits the company's competitiveness in the market.

To analyze the low rate of complete orders, an Ishikawa diagram was developed to identify the main causes of the problem across six categories shown in Figure 1: material, machinery, method, manpower, environment, and measurement. Subsequently, a Pareto analysis was conducted using data provided by the company, together with observations from site visits and information supplied by the managers, to prioritize the root causes according to their frequency and impact (Figure 2). The results show that the three most critical causes are inadequate plant layout, disorganization in the workplace, and the absence of a defined maintenance plan, which together account for 61.54% of the total impact of the problem. Therefore, this study focuses on applying Systematic Layout Planning (SLP) to address the first two causes, and Total Productive Maintenance (TPM) to address the third.

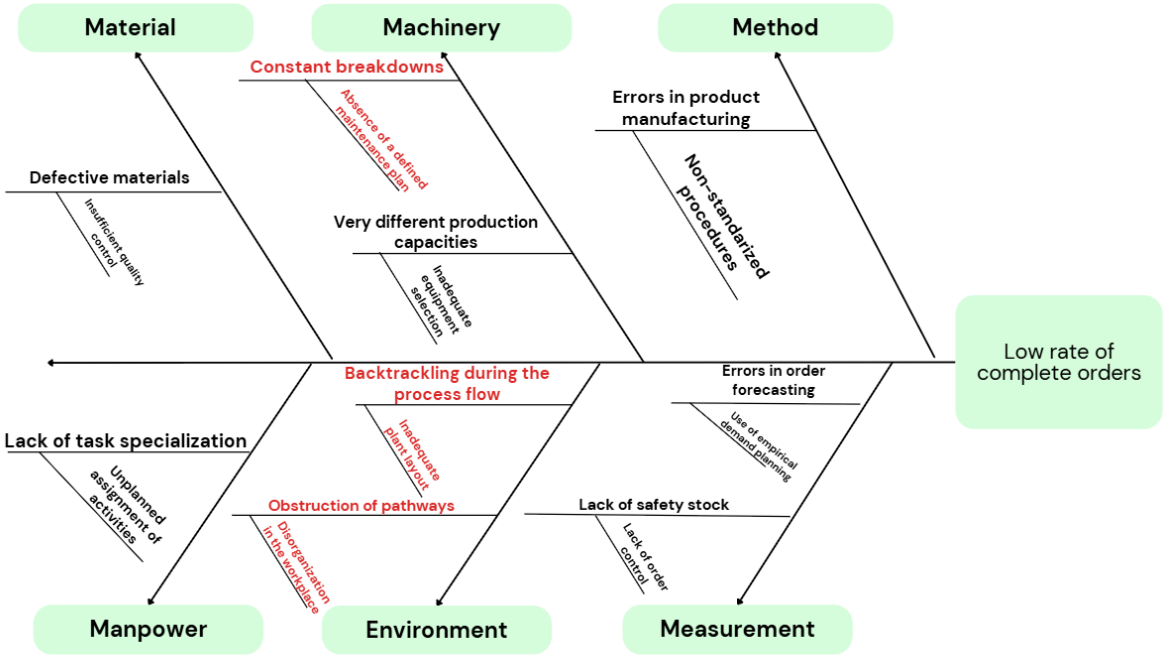


Figure 1. Ishikawa Diagram

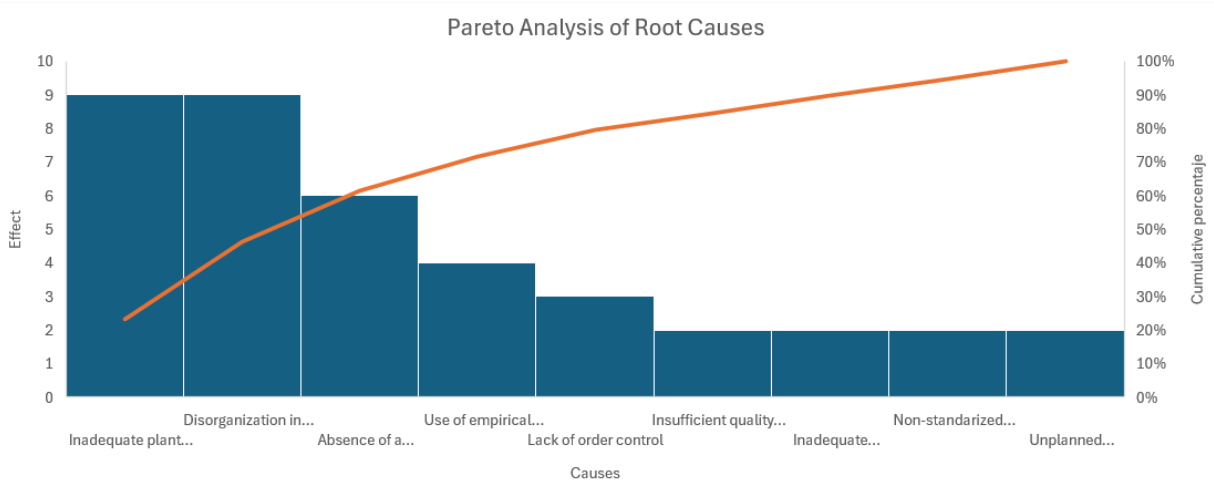


Figure 2. Pareto Diagram

To address this issue, the implementation of two tools is proposed: Systematic Layout Planning (SLP) and Total Productive Maintenance (TPM).

This study is necessary because existing research does not propose the integration of TPM and SLP applied to the problems faced by companies in this sector. Furthermore, the company's low rate of complete orders generates sales losses, penalty costs, and a decrease in customer satisfaction.

In this context, the case study seeks to answer the following research question: How does the application of SLP and TPM impact the increase of the complete order rate in a manufacturing MSE?

Therefore, the main objective of this improvement project is to increase the complete order rate of cardboard binders by 10% in the MSE through the implementation of SLP and TPM.

The following sections present the methodology used to conduct this research, the results obtained, a discussion comparing these findings with previous studies, and finally, the conclusions.

2. Literature Review

2.1 Systematic Layout Planning (SLP)

Systematic Layout Planning (SLP) is a methodology that enables the redesign of workspace based on process flow while considering the weight of transported materials and distances between operational areas [5]. Material handling encompasses the movement of materials from receipt through the manufacturing process to distribution. Inefficient material handling increases production costs, occupies excessive plant and warehouse space, and may delay the delivery of finished products to customers. Therefore, an appropriate plant layout is essential for improving material flow and operational efficiency [6].

An appropriate plant layout allows for the reduction of time and operational effort, as well as the identification and elimination of bottlenecks, which can even reduce the number of machines required [7]. Previous studies report significant improvements following the implementation of this tool, including productivity increases of up to 11% [8], reductions of approximately 12% in travel distances in the production process [9], and decreases of over 80% in the rate of incomplete orders [10]. Also, the implementation of this tool to address plant layout problems resulted in a 67.31% increase in efficiency [11].

2.2 Total Productive Maintenance (TPM)

Total Productive Maintenance aims to increase equipment reliability and productivity in industrial plants by reducing failures. As a strategy for improving operational effectiveness and optimizing equipment performance, TPM focuses on minimizing repair times, eliminating minor stoppages, and reducing overall operational losses [4,12].

The implementation of TPM, complemented by adequate operator training, allows for the control of losses associated with machinery failures [13]. Additional studies indicate notable performance improvements, with reported productivity increases ranging from 21% to 57% [14,15]. Furthermore, the application of this methodology led to enhancements in Overall Equipment Effectiveness (OEE), with observed increases from approximately 2.4% [16] to over 11% across different industrial contexts [17]. Other studies have also reported reductions in idle time following the implementation of TPM [18].

2.3 Integrated Applications of SLP and TPM

Recent studies have explored the combined application of Systematic Layout Planning (SLP) and Total Productive Maintenance (TPM) to improve manufacturing performance in Peruvian SMEs. One study proposed a

process optimization model integrating SLP, TPM, Line Balancing, Kanban, and Poka-Yoke, evaluated through pilot testing, prototyping, and discrete-event simulation, achieving a 14.7% increase in production efficiency [19]. Similarly, another study developed an integrated model combining SLP, TPM 4.0, IoT, and Machine Learning, incorporating layout redesign and SIMIO simulation alongside sensor-based predictive maintenance. The results showed improvements in material handling distances, operational efficiency, and equipment reliability [**20**]. Although these studies demonstrate the potential of combining layout optimization and maintenance strategies, their main focus was on overall production efficiency and equipment performance. Therefore, further research is relevant to evaluate how the joint application of SLP and autonomous and planned maintenance practices can contribute to improving complete order fulfilment in manufacturing SMEs.

2.4 Discrete Event Simulation

Discrete Event Simulation (DES) has been applied to assess productivity improvement strategies in manufacturing and processing systems. It was developed a production improvement model combining Total Productive Maintenance (TPM) and Lean Manufacturing practices, which was evaluated using Arena software. The authors determined processing-time distributions through statistical goodness-of-fit tests and compared the original and proposed scenarios. Their results demonstrated improvements in total productivity and machinery availability, highlighting the usefulness of simulation for quantifying the potential effects of operational improvement strategies [14].

Furthermore, simulation can be integrated with facility layout planning to evaluate the operational performance of alternative plant configurations. It was proposed an integrated decision-support workflow in which Systematic Layout Planning (SLP) was used to develop facility layout alternatives, while DES assessed their performance through indicators such as throughput, machine utilization, and work-in-progress (WIP). Their study highlighted the value of simulation in evaluating layout alternatives and supporting decision-making before physical implementation [22].

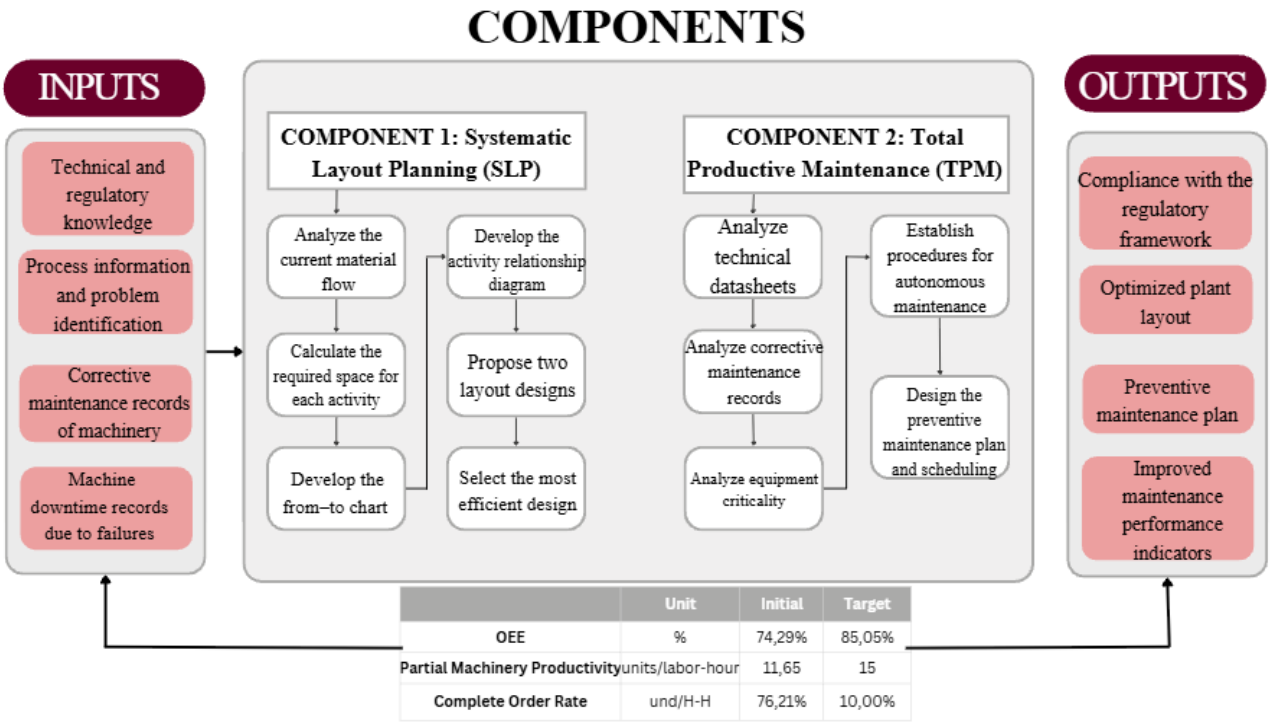
Based on these applications, the present study uses Arena software to evaluate the proposed improvements by incorporating the material flow and transportation times derived from the SLP analysis, together with the maintenance parameters associated with the autonomous and planned preventive maintenance practices. This allows the assessment of the proposed production system through the complete order rate, partial machinery productivity, and Overall Equipment Effectiveness (OEE), comparing the current and proposed scenarios.

3. Methodology

This project is applied to the production line of cardboard binders in a micro and small enterprise (MSE), covering activities from paper coil transportation to final product pallet stacking. The research design is a case study with a simulation-based comparative evaluation of the As-Is and To-Be scenarios, using a quantitative approach. .

The unit of analysis is a binder order; the dependent variable is the complete order rate, and the independent variable corresponds to the implementation of Systematic Layout Planning (SLP) and Total Productive Maintenance (TPM). The study population consists of 932 cardboard binder orders, from which the sample was selected using simple random sampling.

Figure 3 presents the Macro Model, which illustrates the instruments used for data collection, the measures analyzed, and the development of the improvement tools.



	Unit	Initial	Target
OEE	%	74,29%	85,05%
Partial Machinery Productivity	units/labor-hour	11,65	15
Complete Order Rate	und/H-H	76,21%	10,00%

Figure 3. Macro Model of the Solution

For data collection related to SLP, time measurements were conducted using a stopwatch, and distances within the plant were measured using a measuring tape.

To develop the SLP component, a block diagram was first developed to identify the loads transported between activities. A Process Analysis Chart (PAC), shown in Figure 4, was then prepared to determine the processing times of each activity and the distances traveled throughout the production process.

Subsequently, a Relationship Chart was developed to establish the required proximity between the different areas based on the importance of their interactions. This chart considers factors such as process sequence, process control, noise and traffic, and shared operating personnel to determine which areas should be located close to one another as shown in Figure 5.

Cardboard Binder Production Process			
	Activity		N°
	Operation		13
	Transportation		15
	Delay		1
	Inspection		3
	Warehouse		0
	Time (s)		1207,67
	Distance (m)		241,9

	Activity Description	Symbols	Time (s)	Distance (m)
1	Transport the paper roll to the cutting machine		180	33,4
2	Cut the paper roll		4,91	
3	Transport the paper		17,42	10,5
4	Arrange and inspect the paper		5,08	
5	Transport the paper to the printer		3,41	1,5
6	Print the binder cover paper		0,28	
7	Transport the printed cover sheets to the table		3,15	1
8	Perform quality control		7,5	
9	Transport the cover sheets to the paper guillotine		8,7	7,5
10	Cut the cover sheets		318,16	
11	Transport the cover sheets to the covering machine		28,53	26,5
12	Transport the cardboard sheets		70,50	60,5
13	Cover the cardboard sheet		10,86	
14	Transport the covered cardboard to the spine-marking machine		4,46	2,5
15	Print the endpapers		0,28	
16	Transport the printed endpapers to the table		3,15	1
17	Perform quality control		7,5	
18	Transport the endpapers to the paper guillotine		8,7	7,5
19	Cut the endpapers		318,16	
20	Transport the endpapers to the endpaper application machine		48,8	30,5
21	Attach the endpapers to the cardboard		13,6	
22	Transport the cardboard binders to the creasing machine		16,5	14
23	Die-cut		3,27	
24	Fold the cardboard binders		2,29	
25	Place the cardboard binders on pallets		2,5	1
26	Transport the rivets and rings		72,5	41
27	Transport the cardboard binder to the ring-binding machine		5	2
28	Insert the rings		2,83	
29	Press		5,34	
30	Attach the fastener		31,97	
31	Transport to the pallet		2,32	1,5

Figure 4. Process Analysis Chart

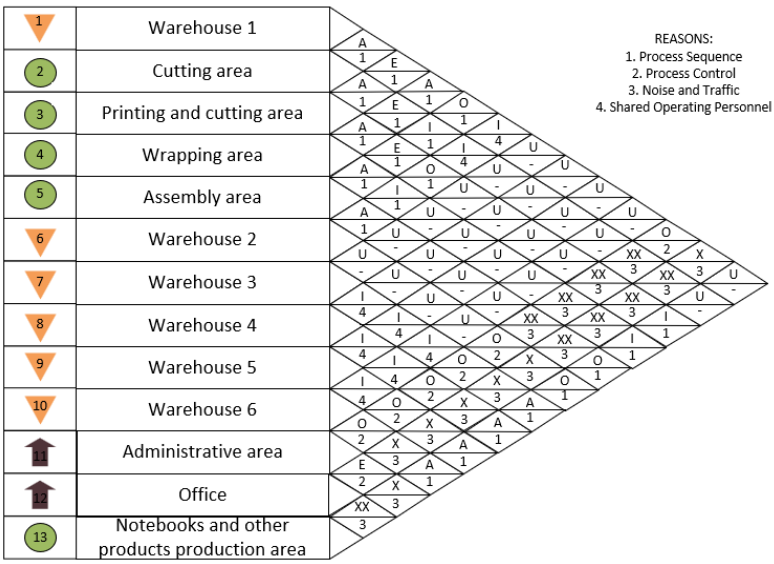


Figure 5. Relationship Chart

For the second component, TPM, the technical datasheets of the machinery were analyzed, and records of failures and repairs were organized to determine the criticality of the machinery used in the production. This analysis was based on the number of hours lost annually due to corrective maintenance. According to Figure 6, the riveting machine is the second that generates the most downtime due to corrective maintenance. The folder-making machine and the printer were not considered because the company did not allow a pilot test on these machines, as they did not want to interrupt their operation and risked delaying production.

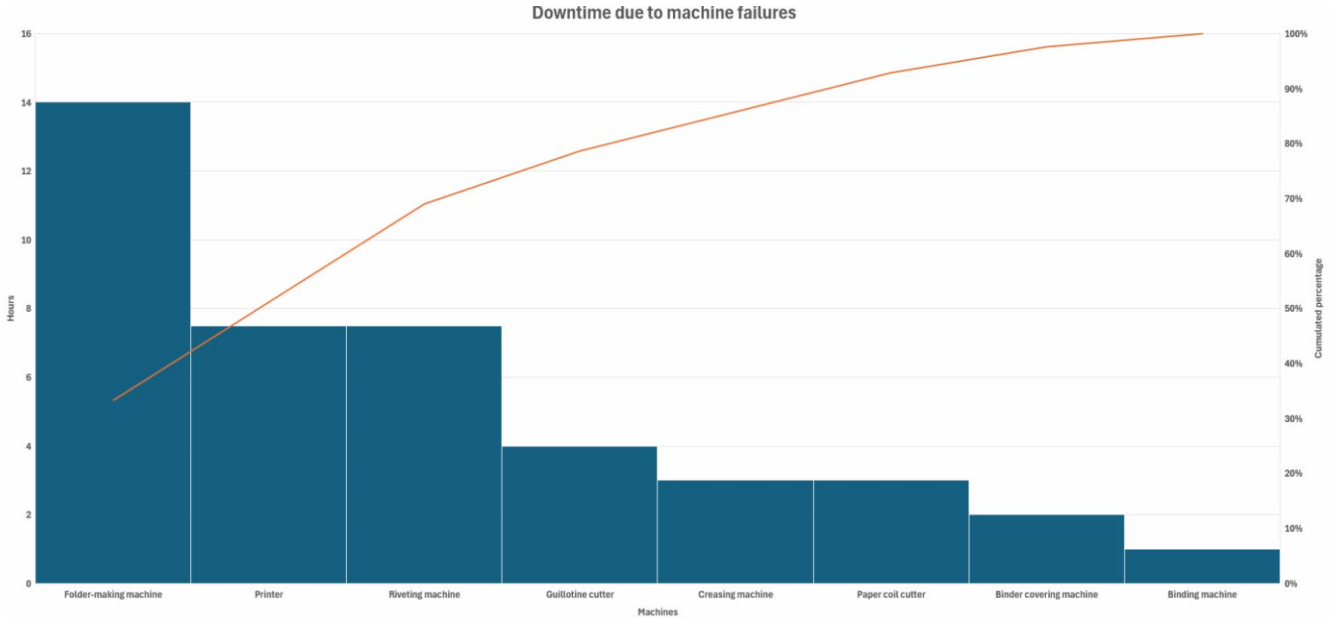


Figure 6. Pareto Analysis of downtime due to machine failure

Based on this analysis, specific autonomous maintenance procedures were developed for each machine, considering the inspection, cleaning, lubrication, and other maintenance activities required for proper operation. These procedures also established that any detected failures must be immediately reported to the plant supervisor or the person responsible for maintenance and repairs. Additionally, a flowchart was developed for each machine to illustrate the sequence of steps involved in autonomous maintenance and guide operators through the procedures. However, the practical pilot application was limited to the riveting machine, which was selected based on the equipment criticality analysis. Figure 7 illustrates the autonomous maintenance flowchart for the riveting machine.

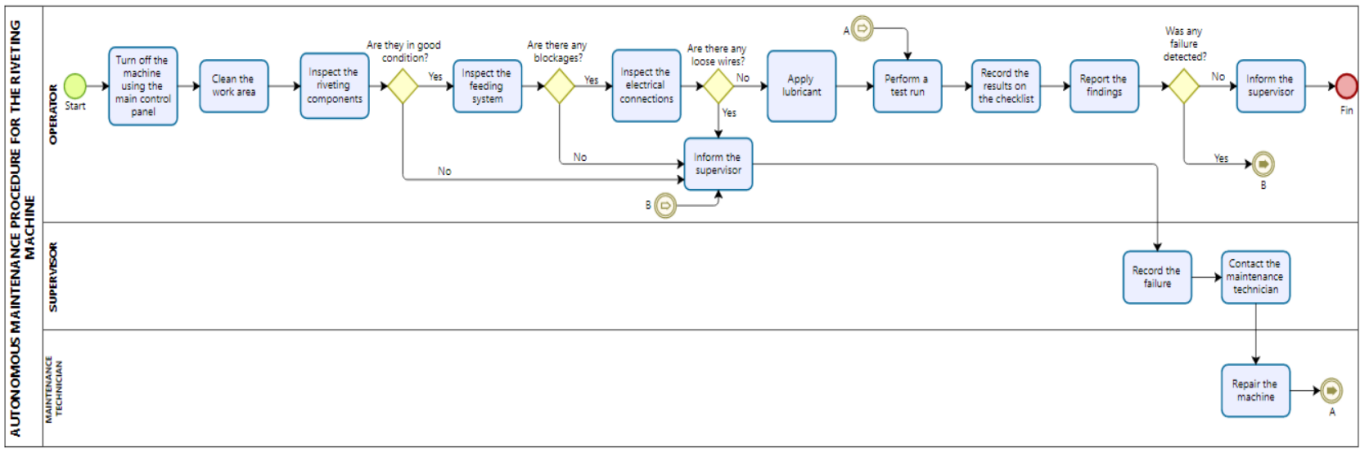


Figure 7. Flowchart of autonomous maintenance procedure for the riveting machine

In addition, during the pilot test conducted on the riveting machine, the time required to perform daily autonomous maintenance was recorded, along with any relevant observations arising during the execution of the procedure.

Following the development of the autonomous maintenance procedures, a preventive maintenance plan was established for the riveting machine. Table 1 presents the planned maintenance activities, including their technical descriptions, responsible personnel, and scheduled frequency, to ensure proper machine operation and prevent equipment failure.

Table 1. Preventive maintenance plan for riveting machine

Machine: Riveting Machine			
Activity	Technical Description	Responsible Person	Frequency
Ring-binding pressure adjustment	Check the ring-binding pressure and adjust it to prevent failures during the ring-binding process or damage to the rings.	Maintenance Technician	Monthly
Shaft and mechanism lubrication	Apply lubricant to the drive shafts, ring-binding mechanisms, and moving parts to reduce friction and prevent premature wear.	Maintenance Technician	Monthly
Electrical system inspection	Check cables, switches, and electrical connections to ensure that there are no faults or short circuits.	Electrical Technician	Every two months
Tensioner and brake adjustment	Inspect the tensioners that maintain wire tension and adjust the feed system brakes to prevent blockages.	Mechanical Technician	Quarterly
Thorough cleaning of the ring-binding area	Completely remove material residues, dust, and oil from the ring-binding area, trays, and other internal components.	Maintenance Technician	Quarterly
Technical ring-binding test	Perform a test cycle using material to verify ring-binding quality after maintenance.	Maintenance Technician	After each maintenance procedure
Ventilation and cooling system inspection	Inspect the fans and ducts to ensure that there are no obstructions and that the system is operating properly to prevent overheating.	Maintenance Technician	Semiannually

Finally, Arena simulation software was used to model the production process and evaluate its behavior under different operating conditions. This simulation model was used to avoid implementing changes directly in the physical production environment [19].

To select the most efficient layout proposal based on the load and distances, a matrix analysis was developed to determine the total effort throughout the current layout and the proposed alternatives.

4. Results

4.1 Comparison of Layout Proposals

The distribution analysis was carried out using the Guerchet method, which determined that a total area of 467.51 m² is required in the plant to optimize the distribution of the operations involved in the cardboard binder production process. Currently, the factory has a production area of 709.84 m² on the first floor, allowing the remaining space to be used for the storage and distribution of the company's other products.

Table 2. Effort Matrix Results Comparison

Layout	Effort Matrix (t-m)
Current	10,132.75
Proposal 1	7,540.06
Proposal 2	7,456.31

Based on these results shown in Table 2, Proposal 2 should be selected for the plant redistribution, as it generates lower material handling effort compared with both the company's current situation and Proposal 1. It is also worth highlighting

that the high effort currently incurred by the company is mainly due to the transfer of levers from warehouse 2 located on the second floor to the assembly area. Therefore, the proposed layouts prioritize placing these components closer to the assembly area.

Figure 8 presents the layout proposed using the SLP methodology. This design eliminates the backtracking identified in the current process and reduces the total distance traveled by the operator from 241.9 m to 204.4 m, which demonstrates an improvement in material flow. Likewise, it shows that the main aisles of the factory have a minimum width of 0.9 m and, in the case of door openings, a minimum width of 1 m, in compliance with the regulations established [23].

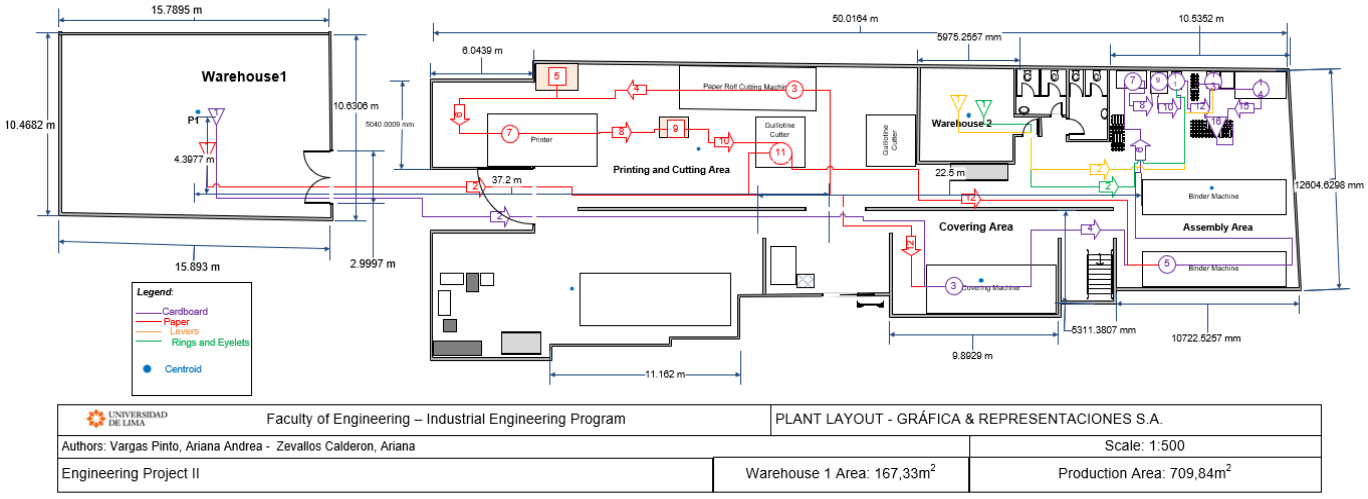


Figure 8. Material flow diagram – Proposal 2

4.2 TPM Pilot Test

A pilot test was conducted on the riveting machine to evaluate the proposed TPM implementation, focusing on autonomous maintenance activities. During the test, the machine's operating times, the frequency and duration of maintenance-related downtime, and detected failures were recorded to assess equipment performance and identify potential improvements.

Table 3 presents some of the maintenance records of the pilot test completed by operators during each autonomous maintenance procedure on the riveting machine. The form is designed to document the date, start and end times, the person responsible, and the corresponding signature, as well as any relevant observations. The plant supervisor's signature is also required to confirm that the maintenance activities have been properly performed.

Table 3. Pilot test records of autonomous maintenance

Machine					
Date	Start Time	End Time	Person Responsible	Signature	Remarks
08/09/25	8:00	8:12	Rosa		
09/09/25	8:00	8:15	Rosa		
10/09/25	8:00	8:12	Rosa		
11/09/25	8:00	8:12	Rosa		
16/0925	8:00	8:10	Rosa		
17/09/25	8:00	8:12	Rosa		
20/09/25	8:00	8:12	Rosa		
22/09/25	8:00	8:12	Rosa		
23/09/25	8:00	8:12	Rosa		
26/09/25	8:00	8:10	Rosa		
27/09/25	8:00	8:13	Rosa		
29/09/25	8:00	8:10	Rosa		
1/10/25	8:00	8:10	Rosa		
2/10/25	8:00	8:12	Rosa		

The records obtained during the pilot test (Table 3) were used to identify the time dedicated to autonomous maintenance. The observed durations ranged from 10 to 15 minutes, with most records around 12 minutes. Based on these data, a triangular distribution with a minimum of 600 seconds, a mode of 750 seconds, and a maximum of 900 seconds was adopted. This distribution was used to model the autonomous maintenance downtime in the Arena

simulation of the to-be scenario, considering one autonomous maintenance per day (Figure 9).

Name	Type	Up Time	Up Time Units	Down Time	Down Time Units
Autonomous Maintenance	Time	1	Days	TRIA(600,750,900)	Seconds

Figure 9. Autonomous maintenance simulation in Arena

4.3 Simulation model

The technological dimension of this study is supported by Discrete-Event Simulation (DES), implemented using Arena software. The simulation model represents the manufacturing process through production orders, processing operations, machines, and operational events, allowing the evaluation of system behavior under different operating conditions. Based on the model shown in Figure 10, the current (AS-IS) and proposed (TO-BE) scenarios were developed and compared. In the proposed scenario, the processing times associated with the autonomous maintenance activities of the riveting machine were incorporated, while the material handling times were updated according to the distances established by the new facility layout proposed through SLP. This approach enabled the quantitative assessment of the combined effects of the proposed layout redesign and maintenance practices before their physical implementation, providing decision-making support for the manufacturing SME.

The processing time distributions were obtained using the Arena Input Analyzer based on time study data collected from the production process. Several activities followed triangular distributions due to the variability observed in manual operations, while other processes were fitted using continuous distributions according to the statistical analysis results.

The simulation model represents the production of binders through a closed-loop order flow. The Create module generates a single order entity, which is prepared through the successive stages of the process. A new order enters the system only when the previous one has been completed. This logic makes it possible to estimate how many orders the plant can fulfill in one year of operation. The total demand modeled corresponds to the orders received in the reference year, since the company only had information for that period.

Lack of stock was measured in terms of production inputs (rings, levers, and fasteners) rather than finished products. When an input runs out in its workstation, the operator must travel to the storage area to bring more units. This replenishment adds the corresponding travel time to the order's cycle time and, at the same time, adds units to the resource, so that the workstation can continue operating. In addition, a second flow represents the paper coil line, which feeds the binder assembly.

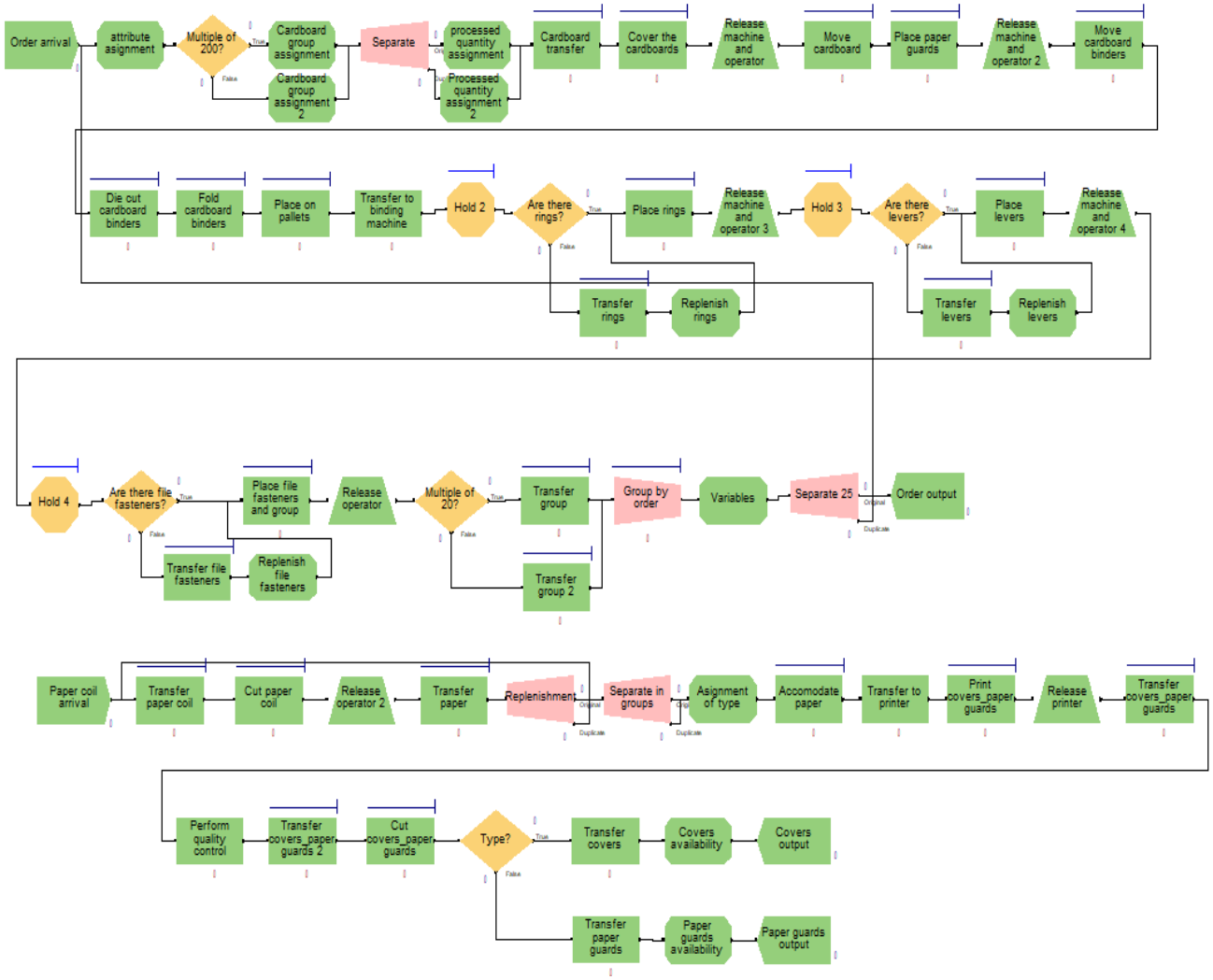


Figure 10. Arena simulation model

Once the model was validated, the number of replications was determined for both models, starting from an initial sample of 10 replications, so that the half-width of each indicator would not exceed 10% of its mean (Table 5 and 6). As a result, 157 replications were required for the As-Is model and 108 replications for the To-Be model.

Table 5. Calculation of the number of replications for the AS-IS model

Indicator	Initial sample	Current half-wisth	Desired half width	N° of replications
Complete Order Rate	10	0.19	0.05	147
Machinery productivity	10	3.45	0.87	157
OEE	10	0.22	0.06	157
Number of cardboard binders	10	96,273	24,346	157

Table 6. Calculation of the number of replications for the TO-BE model

Indicator	Initial sample	Current half-wisth	Desired half width	N° of replications
Complete Order Rate	10	0.15	0.04	108
Machinery productivity	10	2.59	0.99	69
OEE	10	0.16	0.06	69
Number of cardboard binders	10	72,094	27,495	69

Once the number of replications was determined, both models were executed and the results shown in Table 7 were obtained, which evidence an improvement in the three indicators evaluated. The complete order rate increased by 20.98% after the application of SLP and TPM, which confirms the proposed hypothesis that the joint application

of both tools increase the complete orders rate. In addition, partial machinery productivity increased by 20.97% and OEE by 20.98%, indicating an improvement in machine availability and performance.

Table 7. Comparison of the confidence intervals

Indicator	Before	After
Complete Order Rate	[0.40957; 0.49223]	[0.50219; 0.58877]
Partial Machinery Productivity	[7.27276; 8.74044]	[8.91753; 10.45487]
OEE	[0.4622; 0.55548]	[0.56673; 0.66443]

As shown in Figures 11, 12 and 13, the 95% confidence intervals of the As-Is and To-Be scenarios do not overlap for any of the indicators, which indicates that the observed differences can be attributed to the proposed improvements rather than to the random variability of the simulation.

These results provide statistical support for the effectiveness of the proposed SLP–TPM configuration, rather than relying solely on point estimates from the simulation.

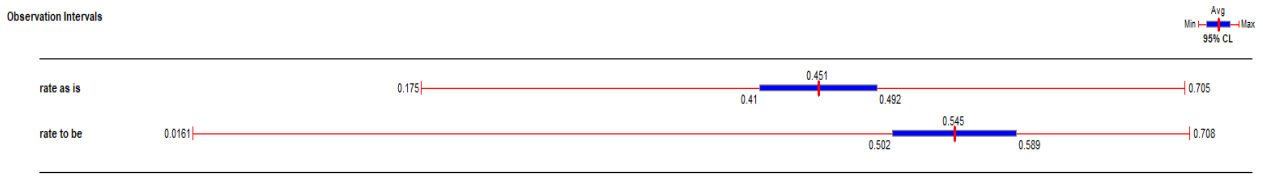


Figure 11. Paired test of the complete order rate



Figure 12. Paired test of the machinery productivity



Figure 13. Paired test of the OEE

4.4 Economic and financial evaluation

The improvement proposal based on the SLP and TPM tools provides several benefits, including an increase in the annual production of cardboard binders, a reduction in material handling times, and a decrease in machinery failures. Consequently, annual revenues are expected to increase, while costs and expenses associated with corrective maintenance and operators' overtime are reduced. However, implementing the proposed improvement requires an initial investment that includes plant redistribution and preliminary studies for both SLP and TPM. For SLP, an initial investment of S/ 29,417.12 is required, while the implementation of TPM requires S/ 14,965.50. These investments consider the following concepts: plant redistribution, preliminary studies, and the resources required for the implementation of each methodology. In addition, annual fixed costs are required to carry out autonomous and preventive maintenance of the machinery, ensuring the continuity and proper execution of the proposed improvements. **As shown in Table 8,** a project cash flow was prepared using a five-year evaluation horizon, as this period allows for the recovery of the initial

investment. Despite the increase in fixed costs, the company continues to generate profits, indicating the project's long-term economic feasibility.

Table 8. Cash Flow

	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Additional cardboard binders	–	68,321	68,321	68,321	68,321	68,321
Selling price	–	4.70	4.70	4.70	4.70	4.70
Additional revenue	–	321,108.70	321,108.70	321,108.70	321,108.70	321,108.70
Variable cost (unit)	–	-3.85	-3.85	-3.85	-3.85	-3.85
Total variable cost	–	-263,035.85	-263,035.85	-263,035.85	-263,035.85	-263,035.85
Fixed expenses	–	-12,200	-12,200	-12,200	-12,200	-12,200
Autonomous maintenance	–	-5,000	-5,000	-5,000	-5,000	-5,000
Preventive maintenance	–	-7,200	-7,200	-7,200	-7,200	-7,200
Initial investment	-32,177.52	–	–	–	–	–
Cash flow	-32,177.52	45,872.85	45,872.85	45,872.85	45,872.85	45,872.85
Cumulative cash flow	-32,177.52	13,695.33	59,568.18	105,441.03	151,313.88	197,186.73

The economic analysis was conducted by estimating the Net Present Value (NPV) and Internal Rate of Return (IRR), using an opportunity cost of capital (COK) of 8.63%. Additionally, a risk analysis was performed using @RISK with 1,000 iterations to evaluate the variability of the financial results. Figure 14 shows an average simulated NPV of S/ 147,974.86, with a standard deviation of S/ 66,996.77. The results indicate that approximately 98.9% of the simulated outcomes have a positive NPV, while only 1.1% are negative. Similarly, Figure 15 presents an average simulated IRR of 140.02%, with a standard deviation of

54.45%. Approximately 99.3% of the simulated IRR values are positive, whereas 0.7% are negative. These results indicate a high probability of economic profitability and suggest that the project remains financially viable under uncertainty.

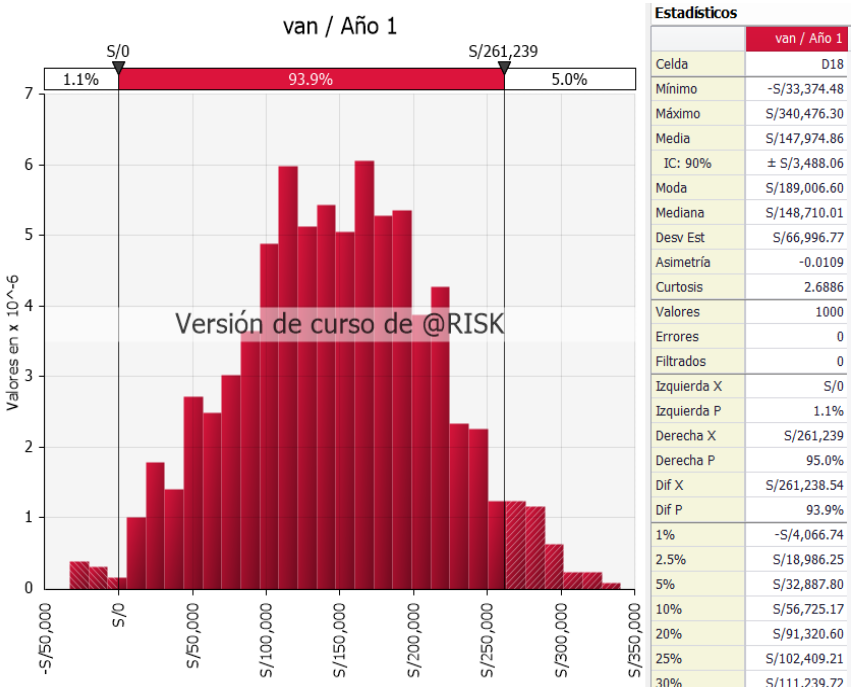


Figure 14. NPV Distribution Chart

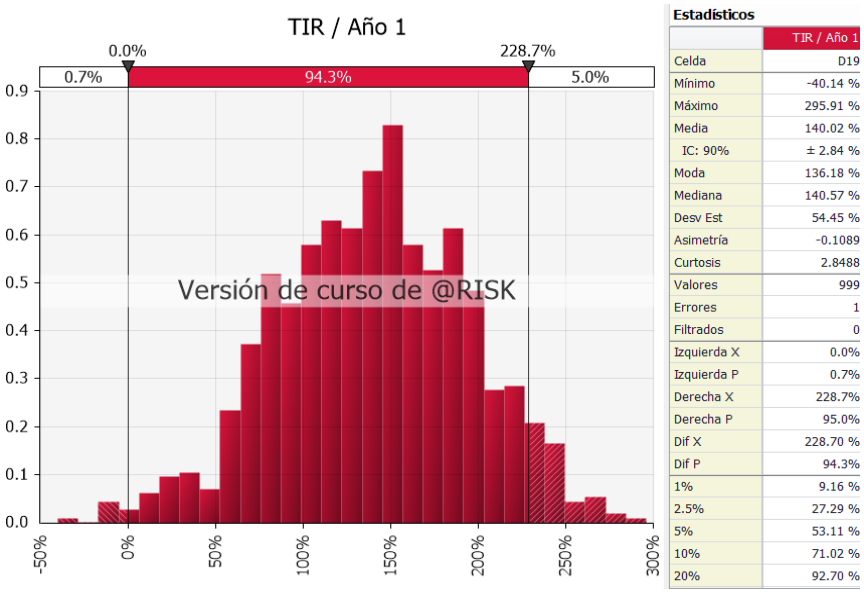


Figure 15. IRR Distribution Chart

Despite the favorable projected financial indicators, the company did not have sufficient budget availability to implement the proposed layout during the study period. Therefore, the positive NPV and IRR reflect the project's estimated economic feasibility rather than the company's immediate financial capacity to undertake the investment.

4.5 Environmental Impact Assessment

For the environmental impact assessment of the project, a Leopold matrix was developed. The results indicate that, although negative impacts were identified, mainly related to solid waste generation, the overall impact of the project was positive, with a net score of 14. This is mainly attributable to the positive impact of the project activities on the improvement of working conditions.

This result indicates that the implementation of SLP and TPM generates an overall favorable balance. Nevertheless, the identified negative impacts can be mitigated through various measures, such as recycling damaged components, replacing disposable supplies with reusable materials during maintenance activities, and properly segregating waste. These actions help reduce the environmental burden of the production process while reinforcing the positive effects associated with the project.

5. Discussion

The contribution of each methodology to the improvement of Complete orders rate can be explained through its effect on the production process. SLP improves material flow by reducing the operator's travel distance from 241.9 m to 204.4 m, representing a 15.50% reduction. It also decreases material handling effort from 10,132.75 t·m to 7,456.31 t·m, equivalent to a 26.39% reduction.

The application of SLP increased the complete order rate by 82.27% [10]. Although the value obtained in the present case study is lower, the results confirm that the use of SLP effectively contributes to increasing complete orders rate.

Meanwhile, TPM introduces autonomous and planned preventive maintenance practices to improve equipment reliability and reduce maintenance-related interruptions. These changes were incorporated into the Arena simulation model through updated material handling times and autonomous maintenance parameters. The combined effect was evaluated by comparing the production system's performance under the AS-IS and TO-BE scenarios, using the Complete Order Rate, partial machinery productivity, and OEE as performance indicators. Likewise, previous studies have reported improvements in OEE following the implementation of TPM and Lean Manufacturing tools. An increase in OEE from 58.50% to 79.75%, corresponding to a 36.32% improvement, was reported in a cardboard box manufacturing process [4]. Similarly, an increase from 67.42% to 77.80%, equivalent to a 15.39 % improvement, was obtained in Indonesian automotive MSEs following the implementation of TPM [17]. Another study reported an increase in OEE from 60.70% to 65.30%, representing a 7.58 % improvement, after implementing TPM [18]. In a Peruvian metalworking MSE, the implementation of Lean Manufacturing and TPM tools increased OEE from 63.37% to 78.45%, corresponding to a 23.79% improvement [16]. Furthermore, the application of Lean tools, including TPM and 5S, in the cement industry increased OEE from 65.59% to 68.12%, representing a 3.86% improvement [13]. Overall, these studies reported an average OEE improvement of 10.76%, whereas the present study achieved an improvement of 20.97%. This result exceeds the average improvement reported in the reviewed studies and indicates that the proposed approach can generate substantial improvements in equipment effectiveness.

With 95% confidence, the results for the three indicators show significant differences between the baseline and proposed scenarios, as the complete order rate increased, while partial machinery productivity and OEE increased.

Despite the improvements obtained, several limitations should be considered when interpreting the results. First, although the proposed plant redistribution is economically profitable, the company did not have the capital required for the initial investment, which prevented its physical implementation and validation under real operating conditions. Therefore, the improvements obtained for the TO-BE scenario were shown through simulation rather than through a post-implementation comparison. Although the simulation results provide statistical evidence of the expected improvements, actual implementation may introduce operational factors that were not fully captured by the model.

Second, the existing physical configuration of the plant restricted the range of feasible layout alternatives. As a result, the SLP analysis was conducted within the facility's existing infrastructure rather than considering unrestricted layout redesigns. This constraint limited the alternatives that could be evaluated and may have prevented the identification of configurations capable of achieving further reductions in material handling effort. Therefore, the proposed layout should be interpreted as an improvement within the specific spatial conditions of the case study, rather than as an optimal configuration applicable to other manufacturing environments.

Third, the company did not have historical records of standard processing times for the activities involved in cardboard binder production. Therefore, processing times had to be obtained through direct time measurements and subsequently used to define the input distributions for the simulation model. Although the model was validated against the current production system, the absence of established historical standards introduces uncertainty in the input parameters and may affect the accuracy of the simulated results.

Finally, the location of the warehouses could not be modified due to company-imposed operational constraints. Therefore, the SLP configuration focused on improving the internal distribution of production areas while maintaining the existing warehouse locations. Since material movement depends on both the arrangement of production areas and their relationship with storage locations, this restriction may have limited the achievable reduction in material handling effort. The results consequently reflect an optimization under fixed warehouse-location constraints

and do not represent the full potential of a redesign in which warehouse locations could also be modified.

Future research should validate the proposed SLP–TPM configuration through physical implementation, evaluate the sensitivity of the simulation results to variations in processing-time inputs, and investigate alternative layouts under different spatial and warehouse-location constraints. Replication in other manufacturing MSEs would also help assess the applicability of the proposed approach across different production environments.

6. Conclusion

It is concluded that, despite the growth of the sector, companies within it exhibit low productivity. This issue leads to non-compliance in the delivery of accepted orders, impacting not only their economic performance but also their corporate image and customer trust.

The application of SLP specifically helped to reduce the number of backtracking movements and obstructions during the production process, as well as to decrease the effort required. Meanwhile, TPM established a formal maintenance system to ensure the proper operation of the machinery. Therefore, the combination of these tools proves to be ideal for increasing the complete order rate in the case study, as well as partial machinery productivity and OEE.

The combination of both tools is relevant because the reduction in travel time between activities compensates for the time required for autonomous maintenance, ensuring that production performance is not negatively affected. Additionally, the proposed layout reduces the likelihood of blockages during both autonomous and corrective maintenance activities.

The integration of matrix analysis, the pilot test, and process simulation using the Arena software made it possible to corroborate the results of previous studies and to demonstrate that the SLP and TPM tools benefit the company's performance.

Although the results demonstrate significant improvements in productivity and order fulfillment, this study was conducted in a single manufacturing MSE. Future research could apply the proposed approach to different companies and production environments to further validate its applicability.

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