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*Original Article*

# Process Optimization through the Implementation of SLP, Kanban, Poka-Yoke and TPM to Improve Efficiency in a Metalworking SME

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***Abstract -*** *Currently, the metal-mechanic sub-sector faces several challenges in its production processes, such as long lead times, order delays and decreased product quality. These problems have a negative impact on operational efficiency, leading to non-compliance in delivery times and, as a consequence, economic penalties. To address this situation, an exhaustive analysis of historical order records, a time study of each stage of the process, the development of a cause-effect diagram and the application of the Pareto principle (80/20) to identify the most relevant root causes are carried out. Based on this diagnosis, a model is developed that delves into applying Lean Manufacturing tools adapted to medium-sized companies. The tools used in this study include Line Balancing (LB), Poka-Yoke, Total Productive Maintenance (TPM) and Systematic Layout Planning (SLP). The validation of the model is done through a pilot, prototyping and simulations, achieving an increase of 14.7% in the efficiency of the production process. In summary, this model can be implemented in similar environments, requiring only minimal adjustments for its adaptation.*

***Keywords -*** *Process management, Production efficiency, Lean tools, Pilot testing, Simulation.*

## 1. Introduction

Production efficiency is one of the main metrics for companies in the manufacturing sector. A performance benchmark of 62.10%, established by the Sociedad Nacional de Industrias (SNI) [1], highlights the existing gap with the 52.77% currently achieved by the M2T company. This problem is attributed to several underlying issues, such as operator fatigue due to poor ergonomic design, machinery breakdowns, unnecessary trips due to waste in the plant, cross-requests, material requirements, and defective packaging that cause cycle times to be extended and delay the delivery of orders. These root causes can be observed in Figure 1, where an Ishikawa diagram helps classify them into six categories: management, machine, methods, materials, manpower, and environment.

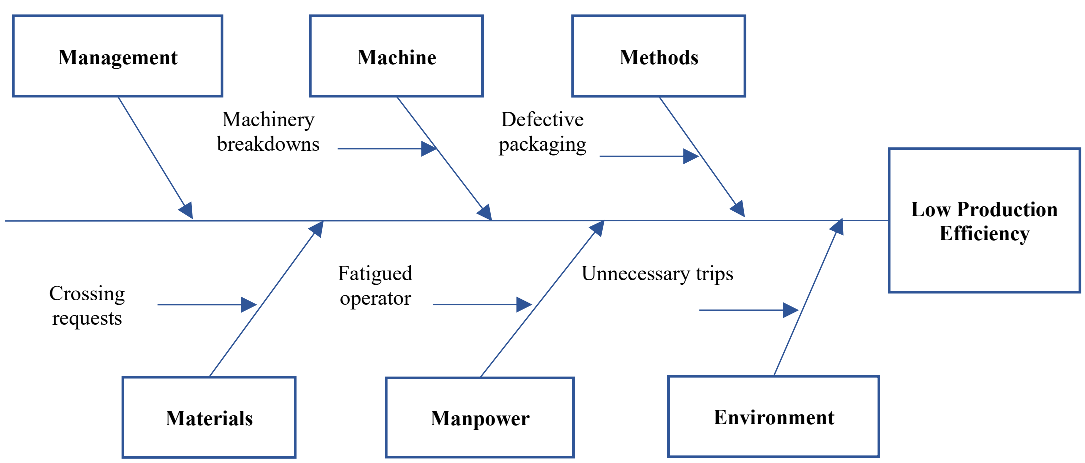


**Fig. 1 Ishikawa diagram of root causes identified**

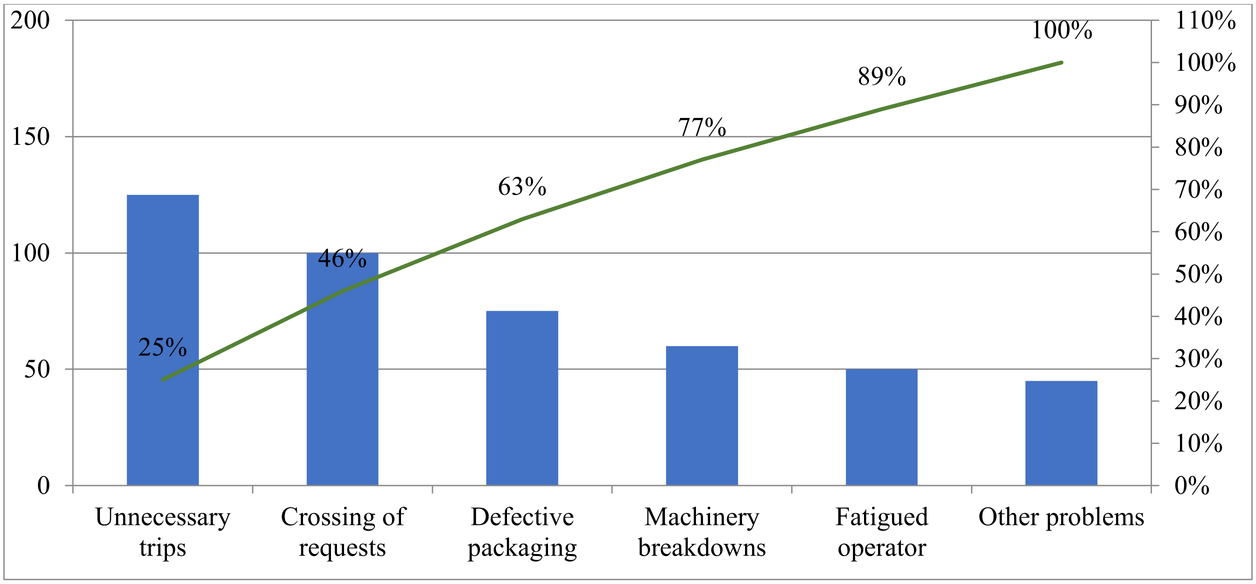


**Fig. 2 Pareto diagram**

Once the most relevant causes of low production efficiency were identified, thanks to the 80/20 principle found in the Pareto diagram, which proved that four of them represented most of the problems: unnecessary trips (25%), crossing requests (21%), defective packaging (17%), and machinery breakdowns (15%) were responsible for approximately 80% of the efficiency issues. In Figure 2, the Pareto shows which causes should be addressed and prioritized. Previous studies present models focusing on improving and increasing efficiency based on the identified factors or causes. This article presents a case study of a subsector company with a low-efficiency problem and a proposed model to increase this efficiency level using Lean tools.

## 2. Literature Review

### *2.1. About Low Production Efficiency*

Low production efficiency is often attributed to several factors, including worker fatigue due to poor posture, excessive workloads, and equipment malfunctions, all contributing to delays in order fulfilment and increased cycle times. To address these issues, various studies have proposed the implementation of tools such as Value Stream Mapping (VSM) and Kaizen philosophy, aimed at reducing lead times and improving workload distribution to enhance efficiency in furniture production lines [2].

In a related study, Greinacher et al. [3] developed a model grounded in lean principles, focusing on resource optimization. Unlike other approaches, their findings demonstrated not only improved delivery reliability but also significant reductions in production times for metal components, energy consumption, and material costs. Other research has focused on alleviating bottlenecks and improving efficiency through human-robot collaboration. This approach aims to alleviate physical strain on workers and promote better posture, thereby improving performance in manual tasks [4]. Moreover, significant gains in production efficiency have been achieved by reducing machine setup times. One study addressed this issue across six production areas, combining the Single-Minute Exchange of Dies (SMED) methodology with VSM. This integration helped to minimize operational disruptions and ensure that setup times did not hinder overall production flow [5].

### *2.2. TPM Methodology to Reduce Machinery Breakdown*

The TPM methodology aims to increase the Overall Equipment Effectiveness (OEE), which depends on the machinery's performance, quality, and availability, by reducing waste with its pillars. When applied at a beverage company with the integration of the 6s methodology, the performance of the glass line and its availability increased, and the number of defective parts was reduced [6].

On the other hand, the integration of TPM with more than one methodology was introduced in a printing company, which is far from the models implemented in other studies. Consequently, using 5S, Kaizen, and VSM caused the OEE of the printing machinery to improve the company's manufacturing process [7].

As in the first study, the implementation of TPM with 5s in a metallurgical company of Clutches and Hydraulic Controls reduced failures in CNC machinery, and an increase in OEE was verified, where three of the eight pillars of TPM were selected and worked around them one at a time [8]. Finally, another study used the integration of TPM, 5s and Kaizen along with SMED and Jidoka to help reduce lead time, increase OEE, reduce the time of a mold change process, and reduce scrap rate [9].

TPM can also benefit from a sustainability perspective while maintaining its desired productivity improvements. When TPM is applied with an energy efficiency training program, costs on energy usage can be reduced, and productivity increased due to a reduction in equipment abnormalities [10].

### *2.3. Kanban Application in the Control of the Material Flow*

To cope with pull production, strategies are required to plan production and periodically avoid large volumes of inventory. Therefore, applying the Kanban method and other lean manufacturing tools improves production efficiency to deliver timely orders [11]. The application of Kanban together with VSM, SMED, Just in Time (JIT), Kaizen and others to reduce work-in-process inventories, distance travelled by materials and production times by integrating the Lean Manufacturing philosophy and the Facility Layout Design (FLD) method [12]. On the other hand, the application of Kanban, 5s, and TPM allowed the reduction of production times, more than in the previous study, and the waiting times for products in process, as well as increased production rates of pairs of shoes and efficiency [13].

This research focuses on reducing high stock levels and lead times through a Pull system within the paint production line by implementing VSM, SMED and Kanban, orienting them to reduce molding operation times, the machine labor time and Work-in-Process (WIP) between areas such as injection-painting and painting-shipping [11]. Finally, another study supports that applying these tools resulted in increased inventory holding time and units produced by reducing waiting times, waste volumes on the finishing line and production defects [14].

### *2.4. Line Balancing Tool and SLP Methodology for Plant Distribution*

The SLP method seeks to arrange the plant layout more efficiently by prioritizing the production lines with the most traffic. To solve a productivity problem using SLP, more of an ergonomic approach is applied, resulting in a new layout that improves transfer distance, material handling costs and transfer time compared to the current layout. On the other hand, LB is a tool used to calculate the most efficient number of workstations in order to increase productivity. In the same line, standardized work with LB resulted in fewer workers per assembly line and increased production thanks to the reduction of inefficient movements and standard time [15].

Likewise, the application of LB with a discrete event simulation model to measure task times of the same task but with a different configuration in the layout of the straight line and the U-shaped line found that the latter was more efficient in terms of cycle time but had a slower production rate than the other. Hence, the selection of the line configuration depends on the company [16]. Together with the first study, SLP is used to design and optimize the current layout of the facilities and create a sustainable proposal with a reduction of unnecessary movements and long routes, non-value-added activities and the time used to fulfil them as well as an increase in revenue after the application of the model [17].

### *2.5. Implementation of Poka-Yoke to Reduce Human Error*

The Japanese Poka-Yoke technique aims to eliminate human errors during production and improve the quality of finished products. Production delays caused by human errors were detected, so Poka-Yoke was implemented with Lean-Kaizen to reduce lead and value-added times [18].

The combination of Poka-Yoke with standardized work within a manufacturing company generates results that show high levels of non-value-added activities are reduced, as well as an increase in cycle time productivity (efficiency and effectiveness) [19]. Likewise, a study developed in a metal-mechanic company presents the implementation of Poka-Yoke together with Kaizen and Lean Six Sigma that manages to reduce the cycle time produced by rejects and rework of the Polycrystalline Diamond reamer (PCD) product [20].

In contrast to both studies, the application of this technique with SMED, Kanban, 5S and VSM leads to a further reduction in cycle times and a significant increase in productivity and order fulfilment, which has a positive impact on production efficiency and leads to lower penalties for late delivery of orders [21]. Finally, the application of Poka-Yoke focuses on reducing the rate of defective automotive parts products. Combined with Kanban, LB, and 5S integration, station downtime is reduced, resulting in better product quality and increased efficiency [22].

## 3. Methodology

The proposed process management model for process optimization is composed of inputs, three tool components, which are presented in Figure 3, and outputs. The proposed model considers input information such as organizational strategy, plant organization, and knowledge of annual production and inventory disposition in production. Compared to the models found within the literature, these use information such as the main objectives they seek to obtain with their proposal, the use of a diagnostic tool and the identified causes. This emphasizes the proposed model's contribution by considering information and data relevant to the problem.

On the other hand, the components presented in the model include the tools to be used in the proposal: SLP, LB, Poka-Yoke, TPM, and Kanban, grouped by the purpose for which they will be used. The previously analyzed literature also classifies the tools used by the authors in their models by objectives. However, these components have an order of application, whereas, in the proposed model, the components can be applied independently, which generates an added value to the proposal. Finally, in the model output, the main objectives are considered, similar to the models in the literature, such as increased production efficiency, reduced order delivery times and optimized processes. However, the model's outputs differ from the other models because they are not repeated in the inputs. Table 1 compares the input of the proposed process management model versus the literature. For the implementation of this model, validation methods such as prototype, pilot experimentation and simulation were selected to evaluate the efficiency and effectiveness of the tools to help improve the identified problem, which is the low efficiency in the production of the M2T company.

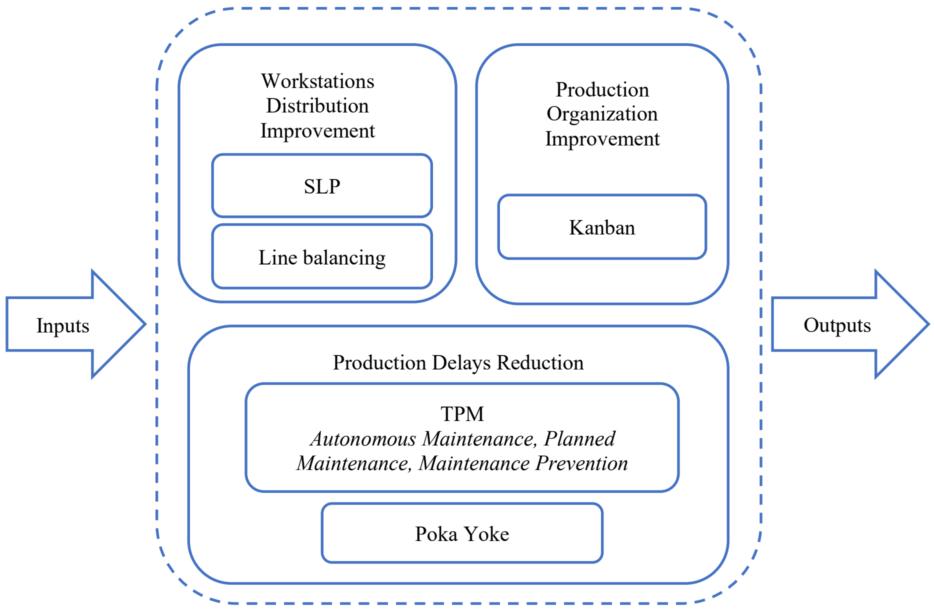


**Fig. 3 Process management model for process optimization**

**Table 1. Comparison between the innovative proposal and the literature**

| Concepts | Process Management Model | Literature Models |
|---|---|---|
| Input data | Information on the company's organizational strategy and plant organization and knowledge of annual production and production stock layout. | Main causes and diagnostic tools |
| Tool components | Tools are classified according to the objectives to be achieved with their application, and their implementation is independent of the previous phases. | Classification of tools by objectives with determined sequence |
| Output data | Main objectives to be achieved with the proper application of the components. | Objectives based on the causes presented as inputs showing redundancy in the model. |

## 4. Validation

### *4.1. Selection*

According to the literature review, four types of validation are present throughout the investigations. Implementations, pilot experiments, simulations and prototypes combined with pilot experimentations can be noted. The implementation methodology has the potential to analyze the whole proposed model and its development in every affected area by the problem. It reaches everyone involved, from personnel to managers [15, 23, 24].

Also, a better perception of achieving the goals can be verified with less uncertainty to propose upgrades in the model [15]. The risks present in an implementation are higher than in every other methodology. These occur because more people are involved, and the whole production needs to be stopped to start the implementation and fix any errors [11]. For the pilot experimentation, it is stated that it can be used to apply their proposed model in a real ambience and if it can reduce the detected problems in specific areas [25, 9]. This validation technique proves that the models are viable and have credibility when presenting results [12, 26]. On the other hand, the posterior implementation of the pilot in different areas or a general approach should present additional adaptations [26, 27].

The prototype approach should take place in a real context and through a field study. This is normally executed with the help of a pilot test in order to visualize if the identified problems are reduced or if any modifications need to be made

[28]. A simulation can also provide quick results that can be analyzed to help with the decision-making process in the implementation of the model [13, 29]. Besides, it helps create different scenarios with different variables for better performance without causing a negative impact on the company processes [16, 22]. However, it is recommended that an implementation be performed to demonstrate and prove that the simulation results are feasible [16]. According to the previous analysis, the selected validation methods that were executed in our study are a simulation, a prototype, and a pilot test.

The prototype and pilot will help with the Poka-Yoke technique validation, and the results obtained will be added to a simulation whose model contains the rest of the tools and methods presented.

### *4.2. Description*

For the Poka-Yoke technique, a prototype with pilot experimentation is required to validate its functionality. This prototype consists of packaging kits for small, medium, and large pieces of the five different products that are being considered in this study.

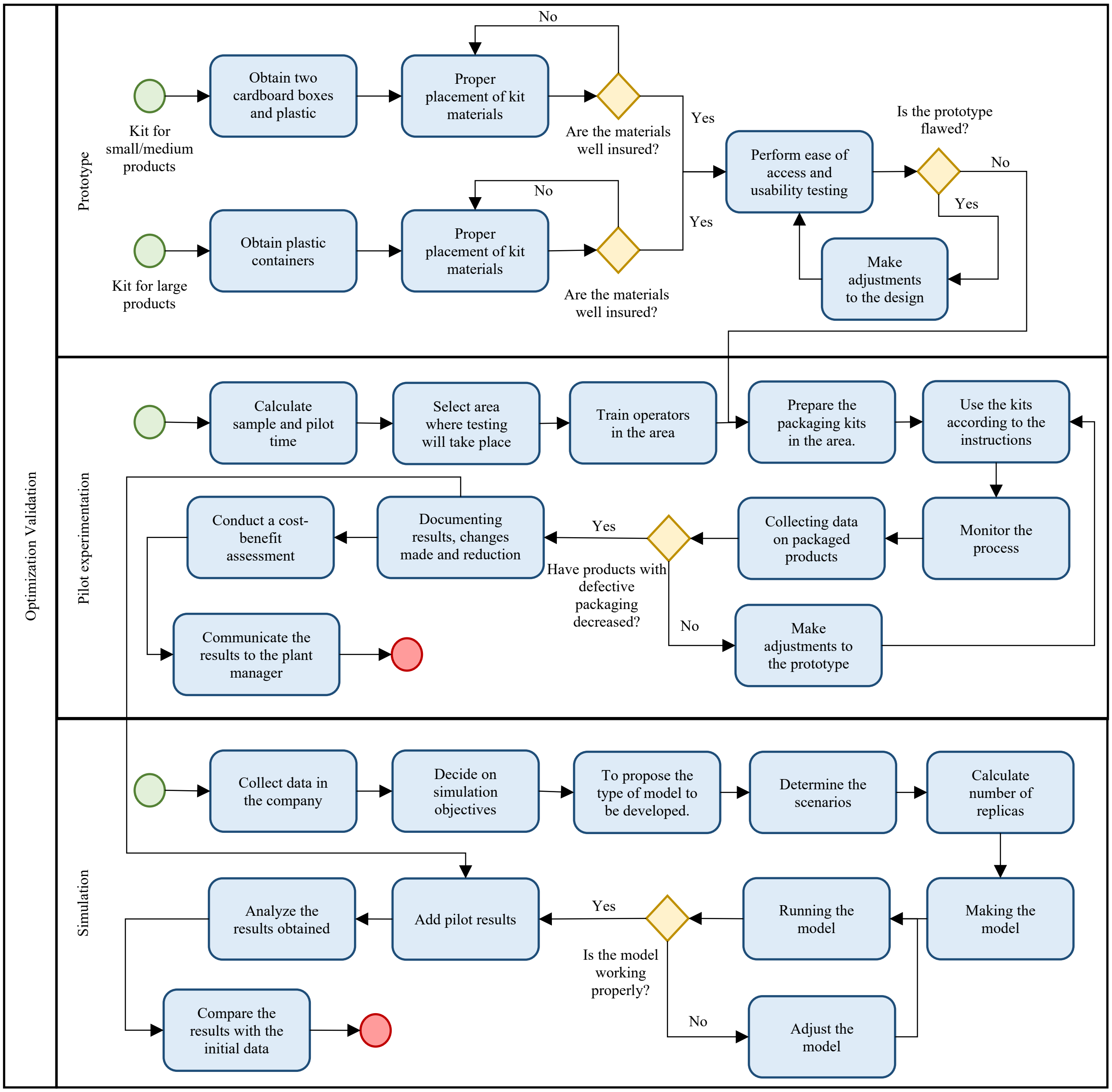


**Fig. 4 Flowchart of the proposed validation methods**

For small and medium pieces, cardboard boxes are used with different dimensions. The small boxes' dimensions are 10cm in width times 15 cm in length and 40cm tall. For the medium boxes, their proportions are 48cm width times 72cm length and 40cm tall. Both kits have the same materials: a cutter, plastic film, scotch tape, their respective label, and polystyrene peanuts. On the other hand, large pieces of kraft paper, security seals, the respective label and a cutter are used.

After collecting all the materials and securing them, tests of access facility and use are done, and if errors are identified, then modifications are made. If not, the pilot test can be carried out. In order to verify the functionality of the packaging kits, a pilot test was developed. Firstly, the sample was obtained through a stratified sample calculation.

Then, the area where the pilot will be implemented is selected, and training on the use of the kits is conducted. Later, the kits are prepared in the packaging area. After, the kits are used with a following of the process to collect all the data of the packed pieces. If the quantity of defective packed products is not reduced, some adjustments are made, and the product is tested again. In the other case, if the defective packed products are reduced, changes, results and reductions are documented.

Finally, an evaluation of costs and benefits is made, and the results are passed to the leadership of the production plant. The simulation starts with data collection from the company, a definition of the objectives, and a proposal for the type of model that will be developed. The scenarios where the simulation will occur are selected, and the number of replications necessary to obtain feasible results is calculated. Then, the model is made and it is tested. In case it does not perform properly, some adjustments are made. If it is correctly working, the results from the pilot are added, and the results are analyzed and compared with the initial data. Finally, all the steps taken in this study, from the prototype to the pilot experimentation and the simulation, can be noted in Figure 4.

### *4.3. Development*

For prototype development, all the materials listed in the validation description are assembled so the kits are ready to test during the pilot experimentation. These materials are located inside a box that has compartments for each of them. Figure 5 shows the box with compartments for the small or medium parts packaging kit, while Figure 6 presents the box for the large packaging kit.

Therefore, functionality tests are performed to verify that the materials are well-secured and do not move when transported to the packaging area. Also, some tests are run with defective products so the correct functioning of the kits can be validated. In the pilot experimentation, a sample is calculated through a sample stratification based on the five different products. First, a main sample is calculated using Equation 1 in which n represents the sample size, N is the total population size, Z is the trust factor, q and p represent the probability of success and failure, respectively, and a value of 50% was assumed for this due to the lack of knowledge of the results and e goes for the error margin where it was assumed to have a value of 5% in order to have a 95% of the trust factor.

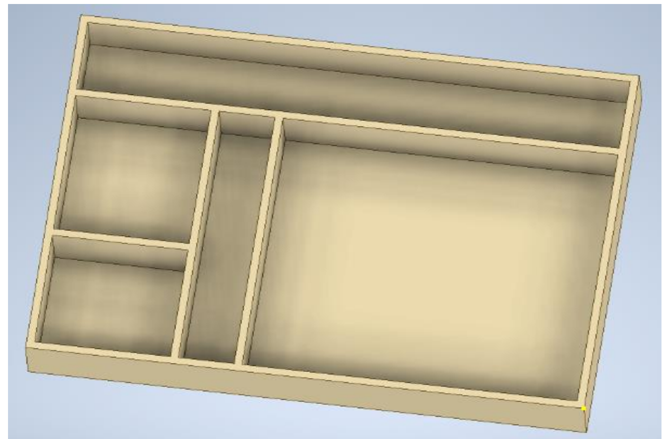

**Fig. 5 Packing kit box for small or medium-sized parts**

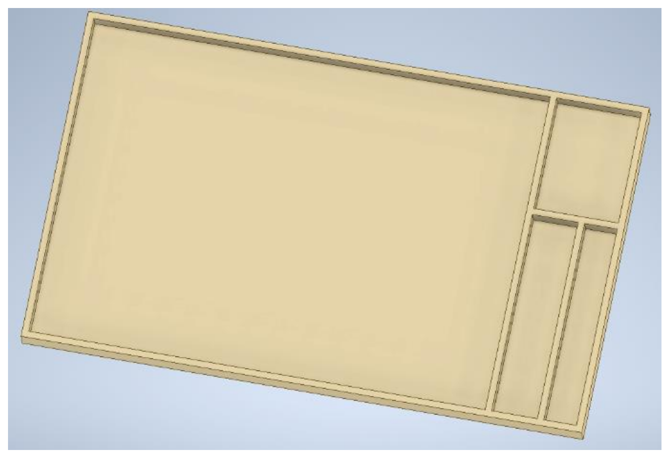

**Fig. 6 Packing kit box for large-sized parts**

$$n = \frac{N \times Z^2 \times q \times p}{e^2 \times (N-1) + Z^2 \times q \times p} \quad (1)$$

$$n = \frac{86350 \times 1.96^2 \times 50\% \times 50\%}{5\%^2 \times (86350-1) + 1.96^2 \times 50\% \times 50\%}$$

$$n = 382.462 \approx 383$$

With the general sample obtained, it is possible to obtain the samples of the five strati in the study. According to Equation 2, where nh represents the sample of each stratus (n1, "Banner supports"; n2, "Display Furniture"; n3, "Advertising Corporeal"; n4, "Booths"; n5, "Carts"), n is the previously calculated sample, N the total population and Nh is the total population of each of the strati.

$$n_h = \left(\frac{n}{N}\right) \times N_h \quad (2)$$

$$n_1 = \left(\frac{383}{86350}\right) \times 18230 = 80.858 \approx 81$$

$$n_2 = \left(\frac{383}{86350}\right) \times 15770 = 69.947 \approx 70$$

$$n_3 = \left(\frac{383}{86350}\right) \times 21697 = 96.236 \approx 97$$

$$n_4 = \left(\frac{383}{86350}\right) \times 16569 = 73.491 \approx 74$$

$$n_5 = \left(\frac{383}{86350}\right) \times 14084 = 62.469 \approx 63$$

Before starting with the field study from the pilot, the selected workers that participate in this study go through training that teaches how to properly operate the different packaging kits.

Before the training, they are graded according to eight different competencies: Attention to detail, manual dexterity, product knowledge, productivity and efficiency, time management, hygiene and cleanliness, quality control, and adaptability.

There were five levels of mastery: incompetent, basic, competent, expert and master. The results of the evaluation can be seen in Table 2.

**Table 2. Results from workers' evaluation**

| Competencies | Worker 1 | Worker 2 |
|---|---|---|
| Attention to detail | Basic | Incompetent |
| Manual dexterity | Competent | Basic |
| Products Knowledge | Basic | Basic |
| Productivity and efficiency | Basic | Basic |
| Time management | Competent | Basic |
| Hygiene and cleanliness | Competent | Competent |
| Quality control | Incompetent | Incompetent |
| Adaptability | Basic | Basic |

**Table 3. Results from pilot experimentation**

| Product | Quantity | Time (minutes) | Defects number |
|---|---|---|---|
| Banner supports | 81 | 2.68 | 8 |
| Display furniture | 70 | 8.23 | 3 |
| Advertising corporeal | 97 | 6.99 | 13 |
| Booths | 63 | 9.51 | 5 |
| Carts | 74 | 9.24 | 7 |

**Table 4. Total standard production time**

| Product | Total Standard Time (minutes) |
|---|---|
| Banner supports | 39.91 |
| Display furniture | 49.48 |
| Advertising corporeal | 41.04 |
| Booths | 75.74 |
| Carts | 64.50 |

After the evaluation, a SWOT matrix and a crossed SWOT matrix were done to work towards the lower scoring competencies, and once they are done, the training takes place, and a data sheet with all the information needed is handed out to each worker. When the training was completed, the application started with two main controls: time and defects. Results showed that as the days passed, and the workers started to feel more comfortable and learned this new packaging technique, mistakes started to decrease along with the time it took them to pack the items.

We can see in Table 3 an average of the results obtained after the pilot. The simulation was done with Arena software, a discrete event simulator. The study began with data collection, including a time study to determine the total standard production time for each of the five products under examination, as shown in Table 4.

After collecting the data, the objectives, scenarios, and model types are selected.For the number of replications needed, a model of the actual company processes was modelled, and it ran 500 times to obtain processes and transfer times with a 5% variation from the current state. With the help of the Input Analyzer, it was possible to obtain the standard deviation and start with the calculation of the number of replicas using Equation 3.

$$N = \left(\frac{Z_{0.95} \times \theta}{D}\right)^2 n_h = \left(\frac{n}{N}\right) \times N_h \quad (3)$$

It was found that the optimum N was 593, which meant that the model needed to be run 593 times to be relevant for the study. For the new model proposed, a time reduction of 15% in the solicitude cross was realized [21], an 11.48% reduction in the cycle time [12], a 30% reduction in transfers [27], and a 2.5% reduction in the delay rate [28]. Also, the results obtained in the pilot were added to their respective module.

The simulation model for the banner, the display furniture, and the corporeal have very similar paths and modules, but their main differences are in the time spent in each module. We can observe this first model in Figure 7.

On the other hand, the carts and booths model vary from the one previously presented, as shown in Figure 8. The times also change per module, and they both have similar structures.

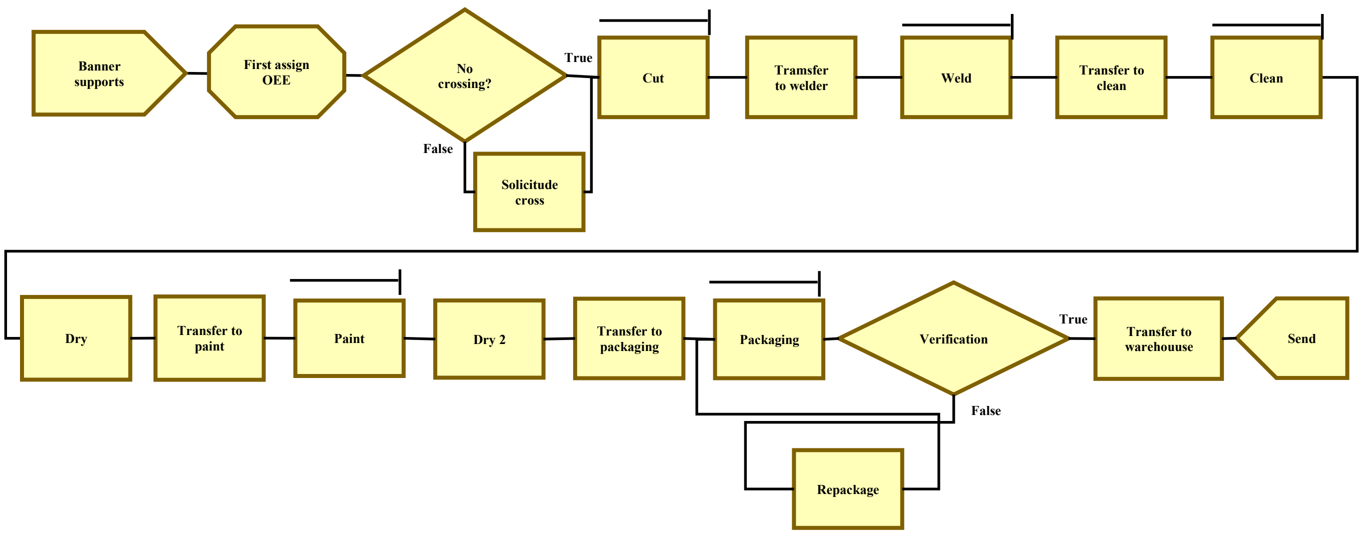


Fig. 7 The banner supports the simulation model

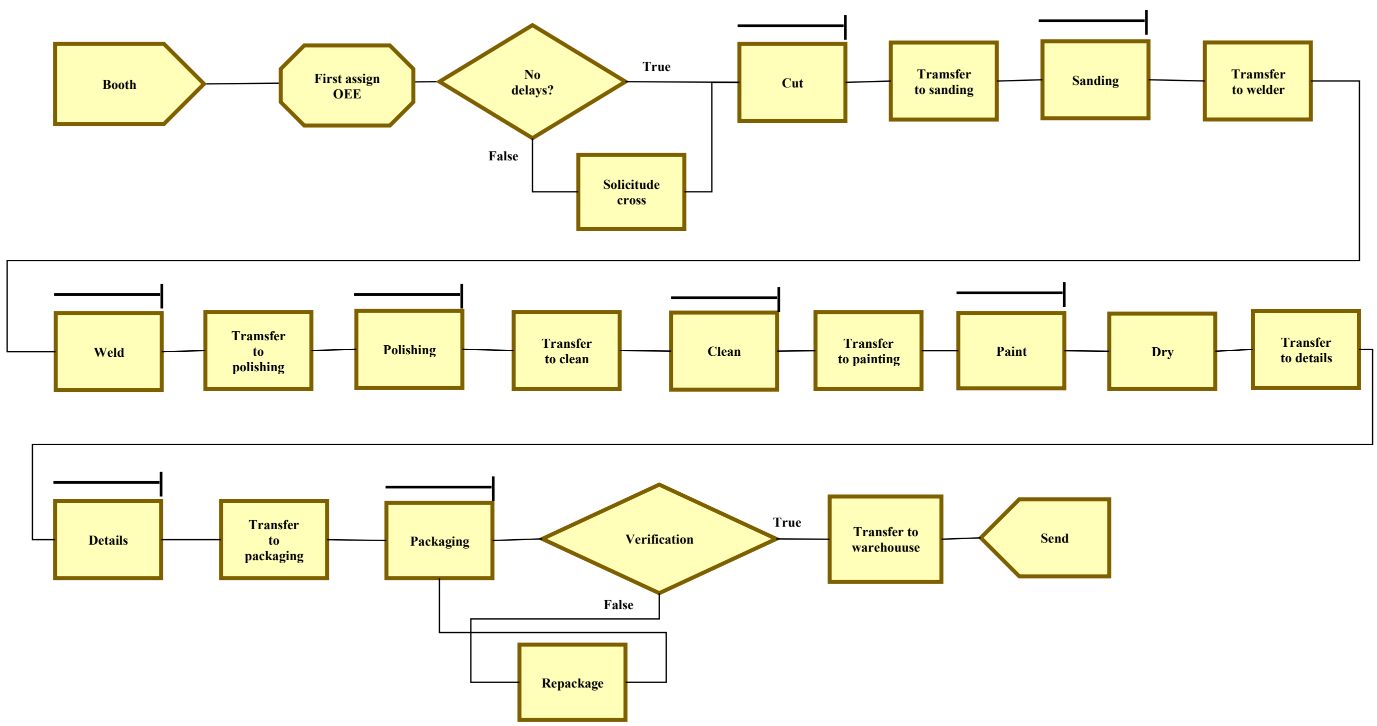


Fig. 8 Booth simulation model

### *4.4. Metrics*

The four key performance indicators used in the study are efficiency, cycle time, OEE, and defect rate to measure the tools' impact. In Table 5, it is possible to compare the company's current situation (As Is) with the results obtained from the simulation (To Be). The main objective of the different tools is: SLP, reduce unnecessary routes; LB, balance times at the workstations; TPM, increment OEE while reducing the number of defective pieces due to machinery breakdowns; Kanban, reduce the shortage of materials due to request-cross; Poka-Yoke, Reduce the number of defective packages due to human error.

Table 5. Results from the simulation vs Current situation

| Tool | Metric | As Is | To Be |
|---|---|---|---|
| Overall | Efficiency | 52.77% | 67.47% |
| SLP | Cycle time | 26.44 min | 18.51 min |
| LB | Cycle time | 13.32 min | 9.32 min |
| TPM | OEE table saw | 57.25% | 79.65% |
| | OEE welder | 54.62% | 66.48% |
| Kanban | Cycle time | 25.11 min | 21.34 min |
| Poka-Yoke | Defective packaging | 17.00% | 9.35% |

Finally, the study's main goal was to increase production efficiency. The simulation showed an increase in production efficiency of 14.7% (i.e., 67.47% - 52.77%).

### *4.5. Economic Impact*

To measure the economic impact of the whole study in the company, five metrics were evaluated: Net Present Value (NPV), Internal Rate of Return (IRR), Benefit-Cost Ratio (BCR), Opportunity Cost of Capital (OCC) and the Discounted Payback Period (DPB). To assure the viability of the project, all these metrics need to fall into an acceptable range. In Table 6, a summary of the cash flow through the years (5 years) is presented and used to calculate NPV, IRR, BCR and DPB.

**Table 6. Cash flow summary**

| Years/Period | Net Cash Flow |
|---|---|
| 2023 | - $ 40,226.54 |
| 2024 | $ 15,574.46 |
| 2025 | $ 20,414.92 |
| 2026 | $ 23,512.58 |
| 2027 | $ 26,610.25 |
| 2028 | $ 29,707.91 |

To calculate the OCC, Equation 4 is used, where "CRP" stands for Country Risk Premium, "β" is the risk factor, "Rf" is the risk-free rate and "Rm" is the expected market return. The calculations yield a value of 9.82% as the OCC. This will be used to validate the IRR value.

$$OCC = R_f + \beta(R_m - R_f) + CRP \quad (4)$$

For the IRR to be acceptable, it needs to be higher than the already calculated OCC. To calculate the IRR, the NPV is obtained using Equation 5. Where "t" is the time, "I" is the initial investment, "CFt" is the cash flow at time "t" and "r" is the discount rate. For the NPV to be viable, it needs to be greater than 0, which is $ 45,527.36 dollars in this study.

$$NPV = -I + \sum_{t=1}^{t} \frac{CF_t}{(1+r)^t} \quad (5)$$

Once the NPV is calculated, it is possible to obtain the IRR with the same formula but replace the "r" with the IRR and solve the equation for what used to be the discount rate, as seen in Equation 6. The result of 43.03% stays over the already obtained OCC, so it is still a viable project from an economic point of view.

$$NPV = -I + \sum_{t=1}^{t} \frac{CF_t}{(1+IRR)^t} = 0 \quad (6)$$

The BCR needs to be greater than a value of 1 to validate the project's viability. Equation 7 is used to calculate the BCR value. The result of 2.13 times shows that the project is also viable due to its value.

$$BCR = \frac{\left(\sum_{t=1}^{t} \frac{CF_t}{(1+r)^t}\right)}{|I|} \quad (7)$$

Finally, the DPB is calculated using Equation 8; in this case, no factor determines if the obtained value benefits the project, but it is shown that it would take 2.35 years to recover from the investment.

$$DPB = Last\ period\ with\ a\ negative\ accumulated\ flow + \frac{|Remaining\ undiscounted\ investment|}{Discounted\ cash\ flow\ of\ next\ period} \quad (8)$$

## 5. Discussion

There has been a vast use of lean tools, techniques, and methods to help solve the detected problems, in this case, SLP, LB, Poka-Yoke, TPM, and Kanban. These are usually used for selected problems and are never worked on the same model [12, 21, 22, 27, 30]. This research proposes that all those tools can be used to obtain significant positive results. While using many tools and techniques does not guarantee a better outcome, the focus of the research is to group them so that different production areas can benefit from the merge and find their appropriate pairs.

As the process management model states, SLP and LB make a great combination to improve the workstation distribution by shortening the distances and transfer times between the different workstations, greatly impacting the current plant cycle time. There is usually a reduction in the cycle time of approximately 11.47% when applying LB [12], while SLP achieves around 8% [3]. Compared to the 30% improvement achieved, it can be stated that the joint implementation of both tools is highly effective.

Also, the three TPM pillars fused with Poka-Yoke present reductions in production delays, which in most cases are caused by defects. In the research context, while Poka-Yoke focuses on the packaging area and TPM in the machinery used for production (table saw and welder), both help with the reduction of defects, the first one with a focus on human errors during the packaging and the second one with breakdowns which result in defective pieces.

The Poka-Yoke technique has demonstrated a reduction of up to 50%, with a maximum initial defect rate of 8% [22]. In the present study, a 9.35% decrease in defects was achieved. The variation in results may be attributed to differences in the type and quantity of defects observed.

An average of 15.91% OEE was reported after the implementation of the model, compared to a 2.03% improvement observed in one of the studies [30]. The TPM applied in this study focused only on three specific pillars, whereas the comparative study implemented the TPM philosophy. Finally, the Kanban contributes to the organization's production improvement. Even though this method is used without a complement, it is given a broader use throughout the production line than in previous studies to avoid the request cross. According to previous studies, Kanban can help decrease production cycle times by 16.96% [21], and 15% was obtained. The results are similar, and the difference might be explained by the processes used to apply Kanban. In addition, Figure 9 shows the improvement that the economic impact has after the complete implementation of the proposed model. A reduction of 72.49% was realized.

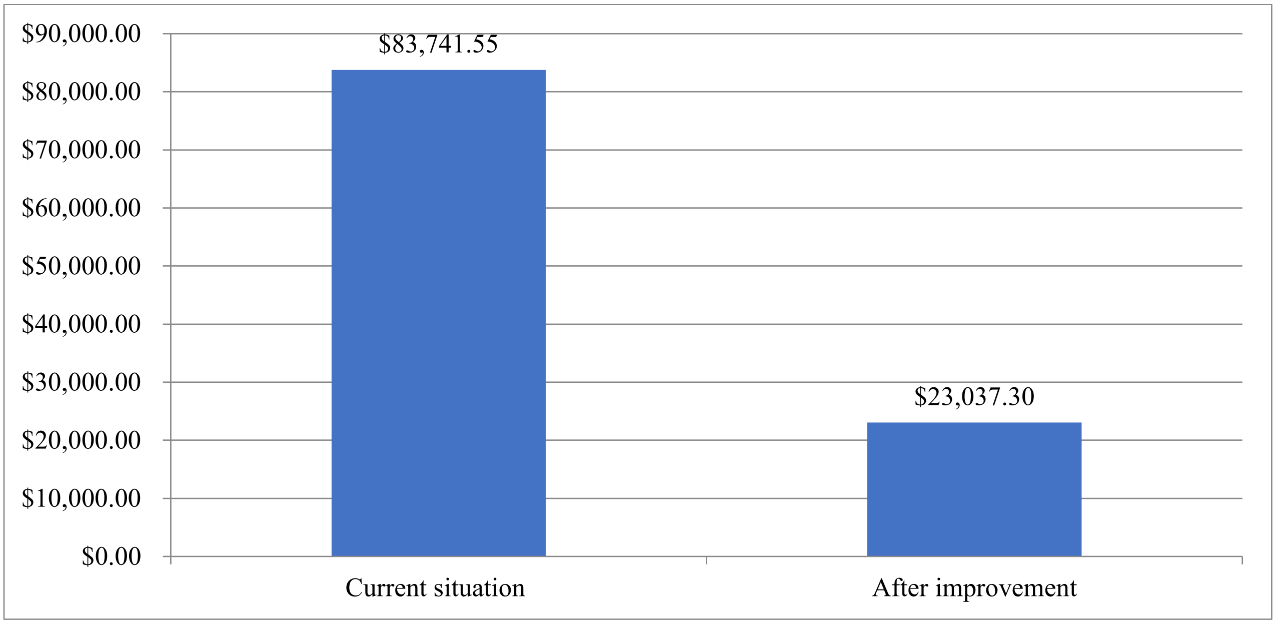


**Fig. 9 Economic impact variation**

## 6. Conclusion

In conclusion, the study identified that the main factors affecting efficiency in the M2T company's production, such as unnecessary routes, border crossings, machinery failures, and packaging defects, represented 52.77% of the causes of inefficiency, directly impacting delivery times.

In response, implementing a model based on Lean Manufacturing tools made it possible to intervene in the critical points of the process. The practical application of this approach showed significant improvements in operational efficiency, validating its effectiveness as a strategy to optimize production flow and reduce delays in order delivery.

The results showed that the economic impact was reduced by 72.49% from the 3.58% of the sales without tax. On the other hand, a reduction of 30% in unnecessary routes was achieved with the help of LB and SLP. Also, it is noted that the shortage of materials in the workstations due to request-crossing was reduced by 15% with Kanban. The defective packaging was lowered thanks to Poka-Yoke by 9.35%. Thanks to the TPM pillars application, the OEE of the welder and the table saw increased by 17.12% on average. Finally, production efficiency was increased by 14.7%.

### *6.1. Future Work and Limitations*

Since the current analysis was validated in an SME, it is recommended that the implementation be carried out on a larger scale with a higher level of production complexity to strengthen the model's effectiveness. In addition, conducting a full pilot implementation of the complete model in a real-world setting would be ideal for testing the model's performance on a production run.

Finally, the proposed model does not consider the variable of social and cultural practices among workers. These factors may have a direct influence on the way the tools and methodologies of the model are interpreted and applied during an implementation, affecting the learning curve and results.

## Data Availability

All the simulation models in Arena Simulation can be found at the following link:

https://upcedupe-my.sharepoint.com/:f:/g/personal/u20201a061_upc_edu_pe/Ei7i4mAq7JtAg3Dkc6CDeJoB1VrxlboXil8nxvNEWYtIbg?e=Ovv3S3

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