5th Asia Pacific Conference on Industrial Engineering and Operations Management
Tokyo, Japan, September 10-12, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/AP05.20240097
Published: September 10, 2024

Optimizing Production Efficiency and Quality in Plastic SMEs: A Lean Manufacturing and TPM Approach

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Abstract

The plastic sector in Peru has experienced significant growth, but SMEs face challenges such as high rates of defective products and low operational efficiency. Lean Manufacturing tools have been shown to improve productivity, but their combined application to reduce defects in SMEs in the plastic sector is limited. Challenges include inadequate machine maintenance and low calibration efficiency, leading to significant economic losses. This research proposes a model combining Lean tools like 5S, Poka Yoke, and Standardized Work with Autonomous and Preventive Maintenance from TPM to organize and optimize production processes. The results show a 2.68% reduction in defective products and a 4.77% increase in machine efficiency. Additionally, 5S audits improved by 41% and setup times were reduced by 26%. These findings validate the effectiveness of the proposed model in enhancing the competitiveness of SMEs in the plastic sector. Academically, this research provides a framework for future studies. Socioeconomically, the model can improve the competitiveness and sustainability of the plastic sector in Peru. It is recommended to explore new directions in the application of Lean Manufacturing and TPM in SMEs to maximize operational and economic benefits.

Keywords
Lean Manufacturing, Total Productive Maintenance (TPM), Production Efficiency, Defective Products Reduction, Plastic SMEs.

1. Introduction
Currently, the plastics sector is one of the most important economic activities in Peru and the world because, according to the National Institute of Statistics and Informatics, the plastics sector had a growth of 4.8% with respect to the level of purchases of durable consumer goods, which includes plastic manufacturing products with 7.5% (INEI 2021). At the same time, around 2,425 companies belonging to the plastics sector were also registered, representing an increase of 31.5%. It should be noted that there are approximately 2,000 plastics companies in Metropolitan Lima. It is also estimated that the plastics sector generates more than 60,000 direct jobs per year. In 2020, it was recorded that less than 3% of the companies in the plastics sector sold more than $50 million (INEI 2021). According to the National Superintendence of Tax Administration, exports of plastic industry products totaled $555 million dollars. On the other hand, according to the SNI, the plastics sector brought as a benefit an increase of 3.5% of the industrial GDP (SNI 2021).

For several years, companies in the plastics sector have been operating below the utilization rate, which represents 71.5%. With this result, it is evident that the process must be improved using new work methodologies. Due to their low production capacity, they generate considerable losses such as fines or loss of the company's customers, which negatively damages the company's image (Alvarado et al. 2018). Research shows that the problems in the plastics sector are caused by lack of knowledge of models or methods for the implementation in the production processes, such as the condition of the machines, the design of both parts and molds, and their maintenance (Chikwendu et al. 2020).

The tools that belong to Lean Manufacturing are widely used by several authors in companies in the plastics sector giving positive results when applied correctly because it reduces production costs, improving productivity. The tools that help to reduce lead times are SMED, TPM, Value Stream Mapping, 5S (Kishimoto et al. 2020). The authors state that there is a direct relationship between the implementation of the tools and how the company operates. The human factor plays a very important role during the implementation process (Simeonova & Nedyalkov 2019), and organizational change starts from the process of transformation in the work culture of the company (Vega & Quiroz 2022).

In the plastics sector, companies usually have difficulty in fulfilling orders due to the low efficiency in which they constantly operate (Hooda & Gupta 2019). Greater focus should be given to teamwork, trying to integrate the collaborators to join the project and make them feel part of it, so that a commitment to constant improvement is created by them since without their joint participation the desired results could not be obtained (Abu et al. 2019). Therefore, the activities to be carried out should not be considered distant from adequate production management, but rather as a competitive advantage (Haddad et al. 2021). Therefore, this article seeks to relate the tools studied to the objectives of increasing productivity. Section II focuses on the state of the art, where the tools used to solve the problems will be explained. Section III presents the validation of the improvement project; the fourth section includes a discussion of the contribution and finally the conclusions of the study.

2. Literature Review

2.1 Lean Manufacturing in the plastics sector

Lean Manufacturing (LM) is one of the most important steps that many companies and industry giants have been implementing to maintain their competitiveness in the global market, which continues to expand exponentially over time. The main objective of the LM methodology is cost reduction by reducing activities that do not deliver or increase the value of the product (Seyed 2016). It is for this reason that LM concentrates on continuous improvement and the elimination of mudas (Buehlmann & Fricke 2016), knowing that many authors have previously highlighted that applying LM helps to reduce or even eliminate overloads, mudas and instabilities in manufacturing processes (Gijo et al. 2018). In addition, it is important to highlight that by applying the LM philosophy, efficiency and productivity also increase and allow a standardization of processes, at least in the short term (Amin et al. 2019).

Likewise, other authors have proposed a combination of a LM model together with Six Sigma, calling it Lean Six Sigma. Six Sigma by itself seeks to reduce or eliminate errors and defects in the processes to increase efficiency and quality, combining it with LM seeks the reduction of losses and instabilities can have a long-lived production model dedicated to constant improvement with an intention of quality almost in its perfection (Farrukh et al. 2022). In addition, Lean Six Sigma was applied in the Supply Chain focusing on organizational changes that allowed an optimization of the supply chain thus improving the productivity of the process (Ifeyinwa & Chukwuebuka 2022).

2.2 Production models based on Lean Manufacturing

Considering past research, the application of different Lean tools such as Value Stream Mapping (VSM), 5S and Standardized Work has allowed analyzing manufacturing processes in small and medium-sized companies, thus observing cycle times and thus being able to determine production capacity, a vital concept for process standardization (Quiroz & Vega 2022). Focusing initially on 5S, other authors have defined the 5S ideology as making the difference between what is necessary and unnecessary in work areas (Gosh 2012). Because the 5S concept is a strategic tool, many small and medium-sized companies, as well as start-up ventures, are constantly applying it to improve their organization and quality. It is so commonly used because of its adaptability to the company's situation and its ability to maintain cleanliness and control (Setiawan et al. 2021). VSM is a tool that looks at the whole situation and does not focus on individual processes but on improving the flow as a whole, but not dedicated to optimization alone. A good use of VSM creates a common language for all production processes in the company, which generates a much simpler decision making, improving VSM as a result (Mahapatra & Mohanty 2007).

For standardized work, several authors have defined it as instructions specifically adapted to the current situation that allows a product to be produced more efficiently (Cespedes et al. 2020). It is defined that the main objective of this tool is to prevent plant operators from performing their responsibilities randomly and irresponsibly (Carrillo et al. 2021).

2.3 Impacts of the Use of Lean Manufacturing

It is known that the sustainability of the Lean concept is the organizational culture it promotes. The concept of continuous improvement involves all members of the company to improve competitiveness. Of all the tools offered by LM, the 5S, Overall Equipment Effectiveness (OEE), Pareto Analysis, Muda Elimination, Kaizen, and VSM are the ones that possess the greatest influence and affect more significantly in their respective environments (Leksic et al. 2020). The authors present case studies where the implementation of LM in a plastics company using 5S, Single-Minute Exchange Die (SMED), Standardized Work, and Visual Management (VM) tools can be appreciated. The impact of the use of LM can be seen in the improvement of the indicators used for the analysis, observing an improvement for OEE of 17%. SMED improved the efficiency and productivity index by more than 60% (Ribeiro et al. 2019). Likewise, the organizational improvement that the LM philosophy promotes helps the working conditions of the operators and other members of the company (Buehlmann & Fricke 2016), which can also be an important factor for the longevity of the organization and an increase in productivity (Saurin & Ferreira 2008).

2.4 Autonomous and preventive maintenance for production processes

According to past research, Total Productive Maintenance (TPM) is a Japanese methodology developed by the need to improve the services and products of several companies (Candelario et al. 2023). The pillars of autonomous and preventive maintenance are fundamental for the complete implementation of TPM and are activities that allow operators to take care of their own machines and equipment (Roosefert et al. 2021). It should also be noted that these two pillars are quite dependent on a culture of order and cleanliness before they can be properly implemented. This is why the 5S are initially implemented in order to promote this philosophy in workers and ensure that the implementation of the pillars is effective (Rohan & Mahesha 2020). Other research reports that the application of TPM demonstrates the importance of having trained personnel who have a thorough knowledge of the machines they work with, how to clean them, and how to maintain them to ensure their performance (Manihalla et al. 2020).

3. Innovative Proposal

3.1 Proposed Model

Using the diagnosis made in a Peruvian company in the plastics sector, it was observed that the main problem they had was the amount of defective products during the production of their products. This in addition to the number of machine stoppages due to some kind of malfunction or need for recalibration. The initial analysis that was performed showed that 80% of the problems were due to manufacturing failures. Using diagnostic tools such as Pareto analysis, the root causes were found to be failures during injection, screen printing, and packaging, with 68%, 22%, and 10% of significance, respectively. To determine the errors more precisely, another level of Pareto analysis was carried out for failures during injection, as this was the most significant, thus obtaining the root causes of machine failures, mold failures, and material failures, with 77%, 18% and 5% of significance, respectively. Machine failures and stoppages were determined to occur due to lack of maintenance, poor calibration, and mishandling of the equipment.

This research project seeks to use the tools of the Lean Manufacturing methodology like VSM, 5S, Poka Yoke and Standardized Work together with 2 fundamental pillars of TPM (Autonomous and Preventive Maintenance) and apply them in the production process for an SME in the plastics sector. The cases shown in the literature above prove that the use of these tools leads to improved efficiency and productivity. However, there is little research about the combination of these tools, much less that they are used to reduce the percentage of defective products in production.

Since the tools improve quality, and performance and reduce the possibility of errors, this research seeks to prove that the use of this combination of tools can significantly reduce the amount and percentage of defective products that result during manufacturing for this sector, in addition to improving the efficiency of the process. Since defective products tend to be mostly reprocessed, they are not considered waste, unless they are in a state impossible to reprocess. These reprocesses mean an additional consumption of raw material since they cannot be reprocessed on their own but must be ground and mixed with virgin raw material, as well as an additional consumption of electrical energy and time that the machine must be kept in operation. For small and medium-sized companies these situations accumulate a significant amount of additional costs that negatively impact their productivity.

Based on the diagnosis performed with the VSM, the proposed model is divided into 4 components. It is important to emphasize that the main objective of this model is to validate the use of the LM model and to serve as a precedent that shows scientific evidence that contributes to the reduction of the number of defective products for the plastics sector. The tools used and implemented in the 4 components (5S, Informative Poka Yoke, TPM and Standardized Work) share the same objective: to reduce defective products and improve the efficiency of an SME in the plastics sector. As it can be seen in **Figure 1**, the first component consists of the implementation of the 5S in order to organize and order the materials and work tools in the production area. The application of the 5S is fundamental for the correct functioning of the following components, so it is applied first in the proposed model. For the implementation of this component, it is necessary to use the following tools:

- Initial audit
- 5S training
- Register and list of objects
- Cleaning program
- Checklist of compliance activities
- Final 5S and future improvement audit

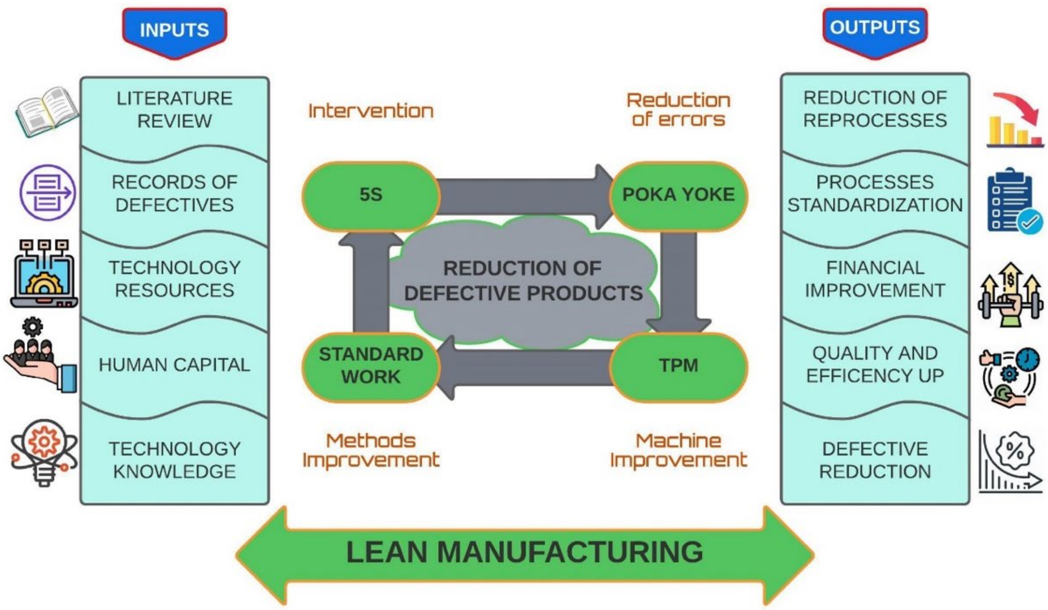

Figure 1. Proposed Model. Adapted from (Mahapatra & Mohanty 2007).

The second component aims at reducing defective products caused by human error and poor calibration. From the VSM it is known that the calibration of injection molding machines is currently done by trial and error, which means a waste of time, raw materials, and electrical energy. Because of this, the use of an informative Poka Yoke allows to offer the machine operators the calibration parameters associated to each specific mold so that they are not wasting material and time calculating the parameters themselves. Since poor calibration may not be noticed until the batch is finished and quality control is performed, meaning that the entire batch may be defective, this component will allow this situation to be eliminated and also reduce machine stoppages due to the need for recalibration.

For the third component we will attack the variable of the problems occurred to the machines during the manufacturing process, mainly the injection molding machines. With the reduction of stoppages due to bad calibration, the next step is to reduce machine stoppages and failures due to lack of maintenance and care. Although the impact on the number of defective products of this component is lower, the use of TPM allows us to increase the longevity of the machines, train operators and promote a culture of care and control. With this, the efficiency and availability of the machines can be improved to a higher level, as well as reducing the sudden expenses due to machine malfunction. Likewise, the quality of the manufactured products is improved, but at a lower level, all these indexes being observed in the OEE indicator associated with the implementation of TPM. Implementing this component generates the involvement of the operators in the maintenance and care activities of their machines, since it is important to carry out periodic inspections to ensure their proper operation and thus encourage their interest in the care of their work environment. The last component reduces time lost due to reprocessing and movements between areas, thus improving the overall efficiency of the process, from the reception of materials to the packaging and storage of finished products. The standardization of the processes makes use of what was applied in component 1 and the operators were trained so that they can make the most of the layout and the order obtained by this component. In this way, anomalous situations can be analyzed before they generate a more significant impact and can be resolved and prevented in the future.

3.2 Proposed model design

Figure 2 shows in detail the sequence that will be followed for the implementation of the model proposed in this research, starting with an analysis with the VSM to determine the current situation of the company, followed by the implementation of the LM tools and the application of autonomous and preventive maintenance. In this way the indicators for effectiveness and defective products can be properly evaluated. The phases presented for the solution model are as follows:

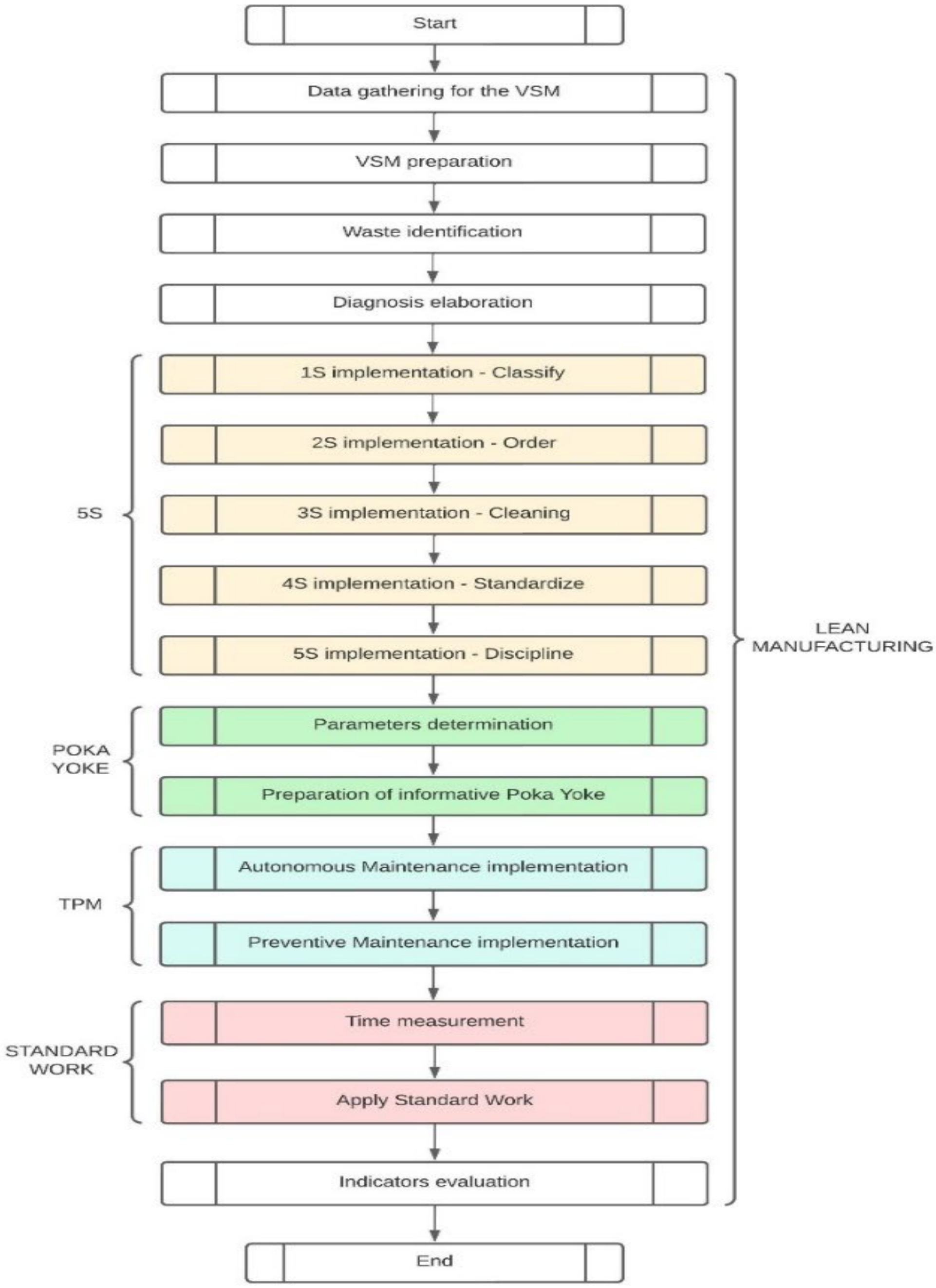

Figure 2. Proposed model

3.3 Model Indicators
The indicators used to analyze and evaluate the work of the proposed model are shown below:

a. Defective products percentage (α)
With the previous analysis it was possible to determine how to evaluate the value of the determined indicator (Khoryanton & Harmanto 2021).

$$\alpha = \frac{\#\, defective\ products}{\#\, total\ products\ produced} \times 100$$

b. Waste percentage (β)
Several studies indicate that this model can reduce this indicator (Realyvásquez et. al, 2018).

$$\beta = \frac{Kg\ of\ discarded\ products}{Kg\ of\ total\ production} \times 100$$

c. Level of 5S Audit percentage (γ)
Some studies indicate that this proposed model serves to improve this indicator (Shahriar et. al, 2022).

$$\gamma = 5S\ questionaries$$

d. Overall Equipment Effectiveness (OEE) (δ)
Many studies indicate that a model such as the one proposed can significantly improve this indicator (Chiarini, 2015).

$$\delta = Avaliability \times Performance \times Quality$$

e. Set-Up time (ε)
Studies indicate how this model can reduce the values of this indicator (Mor et. al, 2018).

$$\varepsilon = Time\ measurement\ (min)$$

4. Validation
4.1 Initial diagnosis of the company under study
The company taken as a case study presents in its processes the research problem that are the resprocesos. **Figure 3** shows the problem tree that represents the detailed diagnosis made in the company to identify the causes and reasons that generate the research problem, specifically the high rate of defective products in a company in the plastic sector. The diagnosis revealed that the defect rate in the company studied was 6.6%, significantly higher than the industry standard of 3%. This discrepancy resulted in an annual economic impact of 906,552 PEN, equivalent to 6.4% of revenues. Three main causes were identified: failures during the process (80.79%), failures during the configuration process (14.51%) and human errors (4.70%). At the root-cause level, the following factors were identified: failures during the injection process (67.80%), failures during the screen printing process (22.30%), failures during packaging (9.90%), omissions of data or calibration errors, and failures in warehouse management. The philosophy and objective of the proposed model focused on using Lean Manufacturing and TPM tools to address these causes, improving the organization and efficiency of the production process, in order to reduce the rate of defective products and their economic impact.

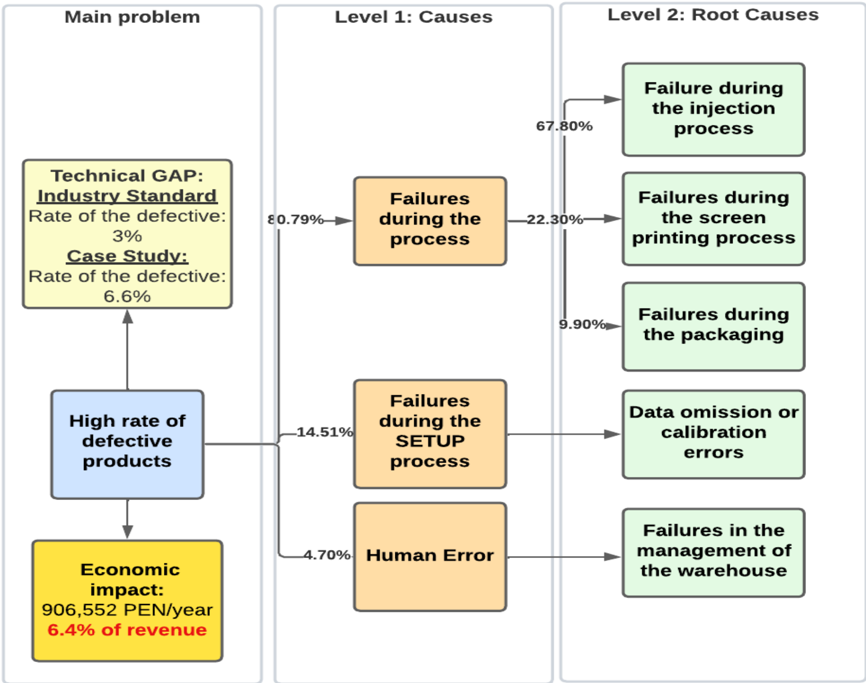

Figure 3. Improved process simulation model

In addition, an initial audit was conducted for the evaluation of each of the S of the 5S methodology. In this way, the value of the cleanliness and order factor of the production plant before the intervention was determined, and the average result of the initial audit was 29%. Knowing that in other investigations it is said that a productive plant should have an average higher than 60%, the situation of the company before the intervention was far from the ideal.

4.2 Validation methodology

To demonstrate that the research is effective and reliable in reducing the number of defective products and improving the company's efficiency, a simulation was carried out using Arena Simulation software. About 30 runs or replications of the process shown in **Figure 4** were carried out. The simulator performed and considered all the variables and indicators involved in the process.

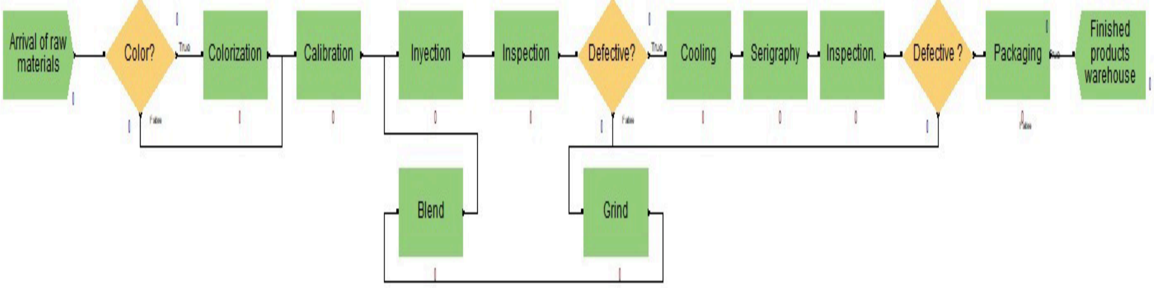

Figure 4. Improved process simulation model

4.3 Design and validation Results

To begin the validation, we started with a pilot test of the 5S methodology implementation. In this way, improvements in the standards applied by the tool, mainly cleanliness and safety, can be evaluated. As shown in **figure 5** where you can see the implementation of the 5S.

Figure 5. Implementation of safety lines for the machines

Likewise, the creation and use of the labels determined for the injection molds and colorants were fundamental to be able to associate them to the informative Poka Yoke that was designed, relating them respectively to the calibration parameters for the machines. **Figure 6** shows the implementation of the Poka Yoke.

Figure 6**.** Rudimentary creation of colorant labels

Specifically, safety lines were implemented for the machines, signs were created for the molds and dyes, the surroundings of the machines were cleaned, the administrative area was organized, and the workers were informed about the importance of keeping their work areas clean and orderly, in addition to acting as a foundation for the implementation of the rest of the tools in the proposal. **Figure 7** shows the implementation of labels for injection molds.

Figure 7. Implementation of labels for injection molds

In order to validate the rest of the results expected by the proposal of this research, the production process was designed based on the product "square rules". The process starts after the reception of raw material, in this case pellets. The pellets are taken to the mixer in case the ruler is of a specific color (in this case green and transparent squares were produced simultaneously). After coloring, the injection machine is calibrated with the previously determined parameters. At the same time, the product mold is transported from the warehouse and equipped on the injection molding machine. While these two activities are taking place, another operator picks up the bag of colored pellets and transports them to the injector where they are added to the machine through its upper hopper. Once these activities are finished, the injection process begins, due to the mold, each injection offers 3 squaring rules simultaneously. When the injection of each group of 3 rulers is finished, they are removed and placed on a table to cool for a few minutes. Once cooled, the rulers are sent to the screen-printing area where they are stamped with the customer's mark, followed by their respective quality control. When it is confirmed that the rulers are optimal, they are packed in a box, each box contains 200 rulers and when each box is filled it is packed and taken to the finished products warehouse to wait for the customer to come for them.

Once the model was designed and explained, the simulation was carried out with the improvements applied. It is important to mention that for the implementation of the 5S of component 1 a pilot test was carried out, as mentioned and explained above, where it was possible to observe the percentage increase (%) of the 5S Audit level up to 70% for the areas where the pilot was applied, as shown in **Figure 8** for each of the S of the methodology that were implemented. In the case of component 2, it was possible to observe the change in the percentage of defective products from 6.6% to 3.92% and the percentage of wastage from 4.19% to 3.56%. For component 3, by applying the 2 pillars of TPM Autonomous and Preventive Maintenance, an improvement in OEE from 57% to 62% was achieved. Component 4 allowed us to standardize the production process and we were able to see a reduction in Set-Up or production preparation times, reducing them by 26%.

Thanks to this model designed in this research and applied with LM tools, it was possible to observe an improvement in the number of defective products by 2.68% and an increase in the efficiency of the machines by 4.77%.

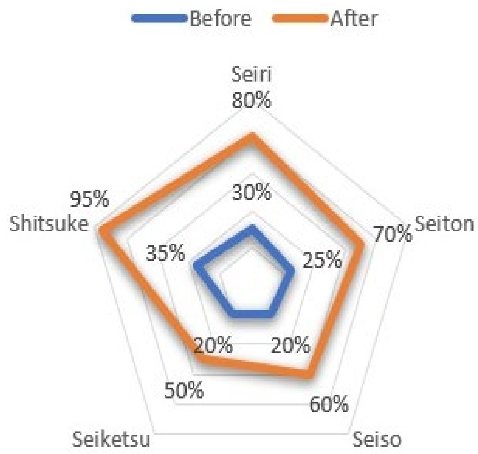

Figure 8. Comparison of 5S audit before and after implementation

5. Discussion and Results

5.1 New potential scenarios

Thanks to the simulation it was possible to validate and prove the effectiveness of the proposed model by reducing time, electricity consumption, raw material costs, thus improving the company's productivity. But to prove that the model is reliable, it is important to demonstrate its effectiveness in different scenarios. Because of this, new scenarios with situations similar to the initial situation will be considered and their effectiveness will be analyzed. The scenarios to be considered were 30cm rulers and 20cm rulers.

- 30cm Rulers
  The injection of 30cm rulers suffers from the same problems as the square rulers due to their low thickness, as well as the handling of the machines. Currently the number of defective products for these rules is 5.74% and the OEE that allows us to measure the efficiency of the machines for this process is 58.94%.

- 20cm Rulers

Like the previous situation, the 20cm rulers also have a high number of defective products, surpassed only by the two previous scenarios. The percentage of defective products is 5.32% and the OEE efficiency is 60.11%.

5.2 Results of Potential Scenarios

By analyzing the new scenarios proposed for the plastics sector for 30cm and 20cm rulers, the improvements that could be obtained by applying the model are shown in **Tables 1 and 2** below.

Table 1. 30cm Rulers Results

Indicator	Current value	Result
Defective Product	5.74%	3.41%
Waste	3.85%	2.98%
OEE	58.94%	65.22%

5.3 Results Analysis

Thanks to the analysis and application carried out in section IV, the validation and verification of the effectiveness of the solution proposed with the model can be evaluated. A reduction in the negative indicators and an increase in the positive indicators could be observed. In order to evaluate and determine the impact of the model presented, it must be validated in the economic and environmental aspect as well since it is important to review the monetary benefits that are possible to be obtained through the project, as well as the consequences of the actions carried out by the proposal on the environment.

Table 2. 20cm Rulers Results

Indicator	Current value	Result
Defective Product	5.32%	3.27%
Waste	3.53%	2.81%
OEE	60.11%	67.44%

5.4 Economic Analysis

It was observed that when applying the model, the cash flow did not obtain any negative value throughout the 12-month evaluation period; on the contrary, the profits observed after the implementation increase as the months go by.Since financing for the implementation was 60% of the budget as considered by the company policy, this debt must be added in the financial analysis of the cash flow. Analyzing the financial flow, we can obtain a financial NPV of 25,019 resulting in an IRR of 39%, which means that our return on investment is positive.In addition, the cost-benefit ratio gives us a value of 2.6, which means that for each sol invested in the proposed model, a profit of 2.6 PEN is obtained. In addition, the return-on-investment time with financing was approximately 5 months, while the return without financing was approximately 8 months.Considering the results obtained, it can be concluded that the investment for the proposed improvement does not produce any risk of loss at any stage of the period, meaning that it is economically viable.

6. Conclusions

The main findings of this study indicate that the implementation of the proposed model, which combines Lean Manufacturing and Total Productive Maintenance (TPM) tools, has significantly impacted the efficiency and quality of production in small and medium-sized enterprises (SMEs) in the Peruvian plastic sector. The results reveal a 2.68% reduction in defective products and a 4.77% increase in machine efficiency. Additionally, 5S audits improved by 41%, and setup times were reduced by 26%. These improvements not only validate the model's effectiveness in optimizing production processes but also highlight its potential to enhance the competitiveness of SMEs in the plastic sector.The importance of this research lies in its ability to provide a robust framework for future studies and practical applications in the plastic sector and other industrial sectors. The combination of Lean and TPM tools offers a comprehensive solution that addresses both workplace organization and machine maintenance, critical factors in achieving efficient and high-quality production. This study not only contributes to the existing body of knowledge but also offers practical guidance for companies seeking to improve their competitiveness and long-term sustainability.

The contributions of this study to the field of industrial engineering are manifold. Firstly, it provides empirical validation of the effectiveness of integrating Lean and TPM tools in an SME context, an area that has been underexplored in the existing literature. Secondly, it highlights improvements in key indicators such as the reduction of defective products, machine efficiency, and workplace organization. These findings offer a foundation for the application of these tools in other sectors and contexts, promoting a culture of continuous improvement and operational efficiency.

In final observations, it is suggested that future studies delve deeper into exploring new combinations of Lean and TPM tools and their application in various industrial sectors. Additionally, it would be beneficial to investigate the impact of these tools on economic and environmental aspects, providing a more holistic view of their benefits. Training and employee engagement should also be areas of focus, as the effectiveness of these tools largely depends on active participation and commitment at all organizational levels. In conclusion, this research makes a significant contribution to the field of industrial engineering, providing a practical and validated model for improving production efficiency and quality in plastic sector SMEs and establishing a solid foundation for future research and practical applications.

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