Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AP06.20250087
Published: August 5, 2025

Application of the 5S and TPM Methodology in the Forming Process for the Manufacture of Gas Cylinders

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Abstract

This study aims to identify bottlenecks in the gas cylinder manufacturing process and implement lean manufacturing tools to improve the OEE (Overall Equipment Effectiveness). The research methodology involved a systematic review of scientific articles related to lean manufacturing and the gas cylinder industry, as well as an analysis of the current state of the industry. The results show that the bottleneck in the gas cylinder manufacturing process was the forming process, which caused rework, failures, and losses. The implementation of lean manufacturing tools, such as TPM and 5S, helped to improve the performance of the operators, reduce the forming machine failures and incorporate capacitive proximity sensors that avoid operator's errors. The main results showed that the principal indicator, OEE was improved significantly, increasing from 63% to 76%, which represents a growth of 13 percentage points. The study recommends the adoption of lean manufacturing practices to optimize the gas cylinder manufacturing process and improve the quality of the final product. The findings of this study can be used by industry stakeholders and researchers to develop strategies for the sustainable development of the gas cylinder industry in Peru.

Keywords

Lean Manufacturing, TPM, 5S, OEE , Efficiency.

1. Introduction

In the latest INEI reports, the commercial sector presents sustainable growth over time, which is very attractive in the business industry. It also plays a fundamental role in the generation of employment and in the contribution of economic growth, regardless of their level, development or political system (ILO, 2023). In Peru, the importance of this sector lies in its contribution to GDP, representing 10.4% and having a growth of 3% compared to the previous period (INEI, 2021). On the other hand, the sector witnessed a negative percentage variation of 13.3% in 2020 and a positive percentage variation of 17.2% in 2021 (INEI, 2023). Likewise, a report carried out by the Central Reserve Bank of Peru indicates that GDP growth expectations for 2025 will be 3% (Banco Central de la Reserva, 2023), which is why companies in this sector must be in constant preparation to meet the needs of new demands and face problems such as a low order fulfillment levels.

According to the literature review, one of the main problems that commercial companies encounter is related to the lack of an inventory structure, which impacts order fulfillment, search times and the amount of obsolete stock. This problem is evidenced in various investigations, for example, in a commercial company located in Lima, which, by not having an adequate classification system, presents high stock levels, obsolescence and high storage costs (Franco et al., 2021). Another investigation carried out in a company that sells agricultural machinery spare parts demonstrates a deficiency in inventory classification since it only presents a mono-criteria classification, which generates inventory overruns and a drop in the order fulfillment levels (Salazar et al., 2019). Finally, a company that sells tires and automotive items in Ecuador presents an empirical definition of the process, which leads to inefficiencies in response times to customers, since time is lost in the search for spare parts (Granizo et al. ., 2018). Therefore, it is important to continue with these investigations, to focus on possible solutions and opportunities for improvement.

The objective of this research is to develop a combination of specific tools that allow for improving the inventory system in commercial companies. In this way, a model is proposed that involves the following tools: 5S, ABC Method, and Systematic Layout Planning (SLP). Likewise, it is important to note that the amount of research focused on inventory optimization in companies that sell spare parts machinery is limited. This scientific article is divided into introduction, literature review, methods, data collection, results and discussion and finally the conclusions regarding the stated objectives.

1.1 Objectives

The objective of this study is to identify the bottleneck in the gas cylinder manufacturing process and apply lean manufacturing tools, specifically 5S and TPM, to enhance both efficiency and quality. Additionally, the study aims to identify the root cause of the improper placement of the disk in the forming machine and measure the impact of the proposed improvements on daily production.

2. Literature Review

2.1 TPM in the metalworking sector

In recent years, Total Productive Maintenance (TPM) has proven to be an effective tool in the metalworking sector, improving productivity, efficiency, and reducing costs in various companies. Various studies have addressed its implementation, demonstrating benefits in operational management and optimized equipment utilization.

A notable case is that of Gutiérrez and Villafuerte (2021), who implemented TPM alongside Lean Manufacturing at FRESEP SAC, a company dedicated to the manufacture of mining spare parts. Before the intervention, overall equipment efficiency (OEE) was 32.86%, but after implementing tools such as 5S and preventive maintenance, OEE increased to 85.58%, also achieving savings of S/ 590,353.55. This study demonstrates the economic viability of TPM in small and medium-sized metalworking companies.

Similarly, García and Rodríguez (2020) analyzed the implementation of TPM and Lean Manufacturing in small companies in the metal-aluminum sector. Their approach allowed for waste reduction and optimization of production processes, increasing the sector's competitiveness. These findings are consistent with the study by López (2019), who applied TPM to a mechanical pickling line at Steel Technologies de México S.A. de C.V., achieving improvements in maintenance planning, reduced operating costs, and increased profitability.
On the other hand, Martínez (2020) focused on the implementation of TPM in a small metalworking company, highlighting the importance of adapting this methodology to different company sizes. Unlike previous studies, which focused on efficiency improvements, this work emphasizes reducing downtime and customizing TPM for SMEs.

A different approach is that of the Institute for Management and Safety in Prevention (2021), which, while not addressing TPM from a production perspective, highlights its relevance in training and occupational risk prevention in the metalworking sector. In this case, the application of TPM is geared toward the safety and ongoing training of workers, showing how this methodology not only impacts productivity but also working conditions and employee well-being.
Based on the analysis of these studies, it can be concluded that TPM is a key strategy for optimizing efficiency in the metalworking industry, but its implementation varies depending on the context. While some studies highlight its impact on efficiency and profitability (Gutiérrez & Villafuerte, 2021; López, 2019), others emphasize its application in waste reduction (García & Rodríguez, 2020) or its adaptation to smaller companies (Martínez, 2020). Finally, the relationship with occupational safety (Instituto de Gestión y Seguridad en Prevención, 2021) demonstrates that TPM can also contribute to improving the work environment in the metalworking sector.

2.2 5S

The implementation of the 5S methodology has proven to be a key strategy in the metalworking sector, enabling improved organization, efficiency, and productivity. Several recent studies have addressed its application in various industrial environments, demonstrating its impact on waste reduction, workspace optimization, and improved operational quality.

A study by Villaseñor and Galindo (2023) analyzed the application of 5S, Andon, and Standard Time in a metalworking company, with the aim of increasing productivity. The implementation led to increased efficiency in the use of materials, reduced production times, and improved process standardization. This study coincides with the review by Burgos Puerta and Ciendúa Monroy (2016), who developed a methodology for implementing 5S in metalworking companies in the Boyacá industrial corridor, Colombia. In this case, the need to involve personnel in the process was emphasized to ensure that improvements are sustainable in the long term.

On the other hand, Romero-Cruz, López-Muñoz, Méndez-Hernández, and Pintor-Tuxpan (2016) evaluated the implementation of 5S as part of a continuous improvement program in the metalworking sector. It was found that, in addition to optimizing the workspace, this methodology improved occupational safety and reduced equipment downtime. Similarly, in a broader study, Universidad Privada del Norte (2020) conducted a literature review on the application of 5S in various industrial companies in Latin America, concluding that its impact on operational efficiency is significant and that its success depends on effective leadership and ongoing staff training.

Finally, Metalmecánica (2024) addressed the implementation of 5S within the framework of current industry trends, highlighting how this methodology is part of the modernization and digitalization efforts in the metalworking industry. In this context, the 5S methodology not only optimizes the work environment but also aligns with broader Lean Manufacturing and digital transformation strategies.

The reviewed studies show that the 5S methodology is a key tool in the metalworking sector, with applications ranging from waste reduction to optimizing production processes and improving occupational safety. While some studies highlight its impact on productivity and operational efficiency (Villaseñor & Galindo, 2023; Romero-Cruz et al., 2016), others emphasize its role in standardizing and sustaining improvements over time (Burgos Puerta & Ciendúa Monroy, 2016; Universidad Privada del Norte, 2020). In all cases, the importance of training and engaging staff is highlighted to ensure that improvements are sustainable and contribute to the sector's competitiveness.

2.3 OEE

In recent years, various research projects have addressed the optimization of OEE (Overall Equipment Efficiency) in the metalworking sector, proposing different methodologies and strategies to improve productivity and reduce losses in industrial processes. In this context, Segovia Villavicencio (2024) proposes the implementation of a Manufacturing Execution System (MES) together with the SMED methodology to increase OEE in the pin area of a metalworking company. His study identifies that 28% of unidentified downtimes significantly affect efficiency, so the digitalization and continuous improvement of processes would allow OEE to be increased from 54% to 65%.

Along similar lines, Canahua Apaza (2021) proposes combining the TPM methodology with Lean Manufacturing principles to improve efficiency in spare parts production within the sector. His goal is to achieve an OEE of 85%, considered a world-class standard, by reducing failures in key equipment such as lathes, milling machines, and cutters. Through preventive maintenance and optimized operating times, the study shows improvements in equipment reliability and availability.

For his part, Alonso Cosío (2021) uses the Lean Six Sigma methodology to reduce the number of defective parts in a drilling process within a steelmaking company. By applying the DMAIC approach (Define, Measure, Analyze, Improve, and Control), variability in processes is reduced and the waste generated is reduced by 50%, which directly impacts the improvement of OEE.

From another perspective, Narro Castillo and Valverde Sánchez (2020) implemented an OEE system to improve productivity in the mechanized field of an agroindustrial company. Their study highlights how the integration of automated systems, such as PLC control, increases operational efficiency and reduces downtime. Thanks to digitalization and the use of Lean tools, they managed to increase the OEE from 63.2% to 88%, demonstrating the effectiveness of automation in improving industrial performance.

Finally, Cáceres Larco and Zegarra Silva (2024) analyzed the efficiency of a mechanical press in the metalworking sector, where they identified an initial OEE of 56.39%, which generated monthly economic losses. To reverse this situation, they implemented a model based on TPM and SMED, complemented by the 5S methodology. As a result, the OEE increased to 88.45%, and setup times were significantly reduced from 24.09 to 12.85 minutes, which improved availability by 40.58%.

3. Methods

This article is a case study, as it focuses on a specific company. In this case, it's a factory dedicated to the production of gas cylinders, and a combination of methods is used to analyze the production process.

The proposed model's input is low OEE levels, reflecting low equipment availability, excessive processing times, and high defect rates. The output is expected to be a substantial improvement in OEE, elevating its value through targeted interventions. Thus, the model is structured in three phases: problem analysis, intervention, and intervention implementation, as shown in Figure 1.

First, a diagnosis of the company's current situation was developed, following the following steps: indicator analysis, root cause diagram, and problem tree. Through this analysis, factors such as work area disorganization, low quality, and process productivity were identified as the main causes of poor performance.

Once the causes were identified, an exhaustive search was conducted for solutions and tools aimed at improving overall equipment efficiency (OEE). As a result, the integrated application of two Lean tools was defined: the 5S methodology, to improve order, cleanliness, and discipline in the work area, and Total Productive Maintenance (TPM), focused on maximizing process availability, quality, and performance.

Unlike other models applied in industries other than heavy manufacturing, this proposal prioritizes improving the work environment as a basis for achieving operational efficiency. Finally, Phase 3 evaluates the results obtained after implementing the tools, comparing the initial OEE levels with the results achieved. With this in mind, Figure 1 shows the proposed model for developing the proposal.

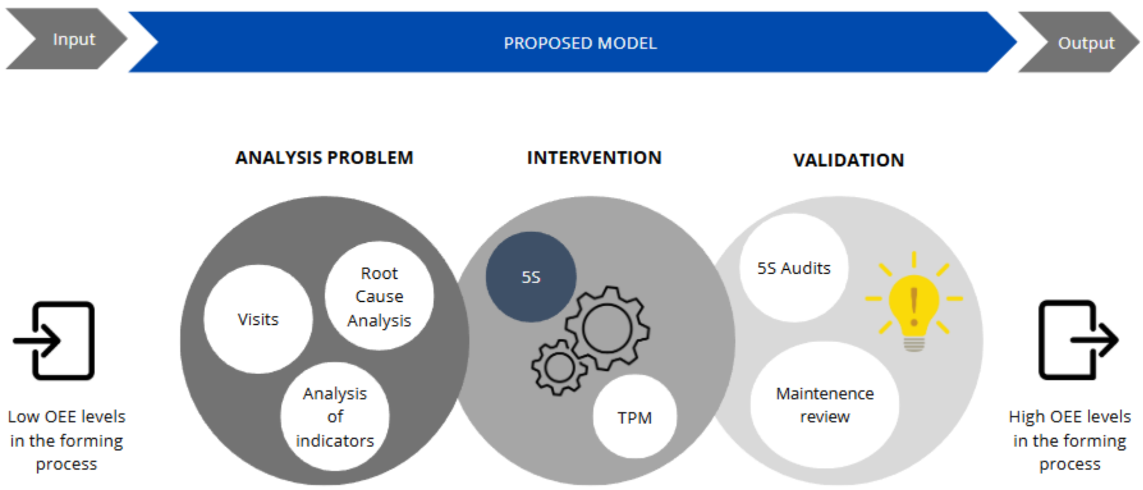

Figure 1. Proposed model

4. Data collection

Data collection for this research was based on the collection and analysis of information from various bibliographic sources (articles, reports, books, among others) to achieve a comprehensive assessment. Additionally, direct visits were made to the gas cylinder factory, where conversations were held with various workers from different areas in order to gain a deeper understanding of the organization and operational processes. As mentioned above, in addition to bibliographic information and field visits, an indicator analysis was used to assess the current status of the forming process. A root cause tree was then used to identify and summarize the main causes of the increased process times.

Once all the information was collected and analyzed, it was determined that it was feasible to apply tools such as 5S to improve organization and order in the work area, and Total Productive Maintenance (TPM) to ensure the proper functioning of critical machinery. Figure 2 shows the process followed to obtain the results of this research.

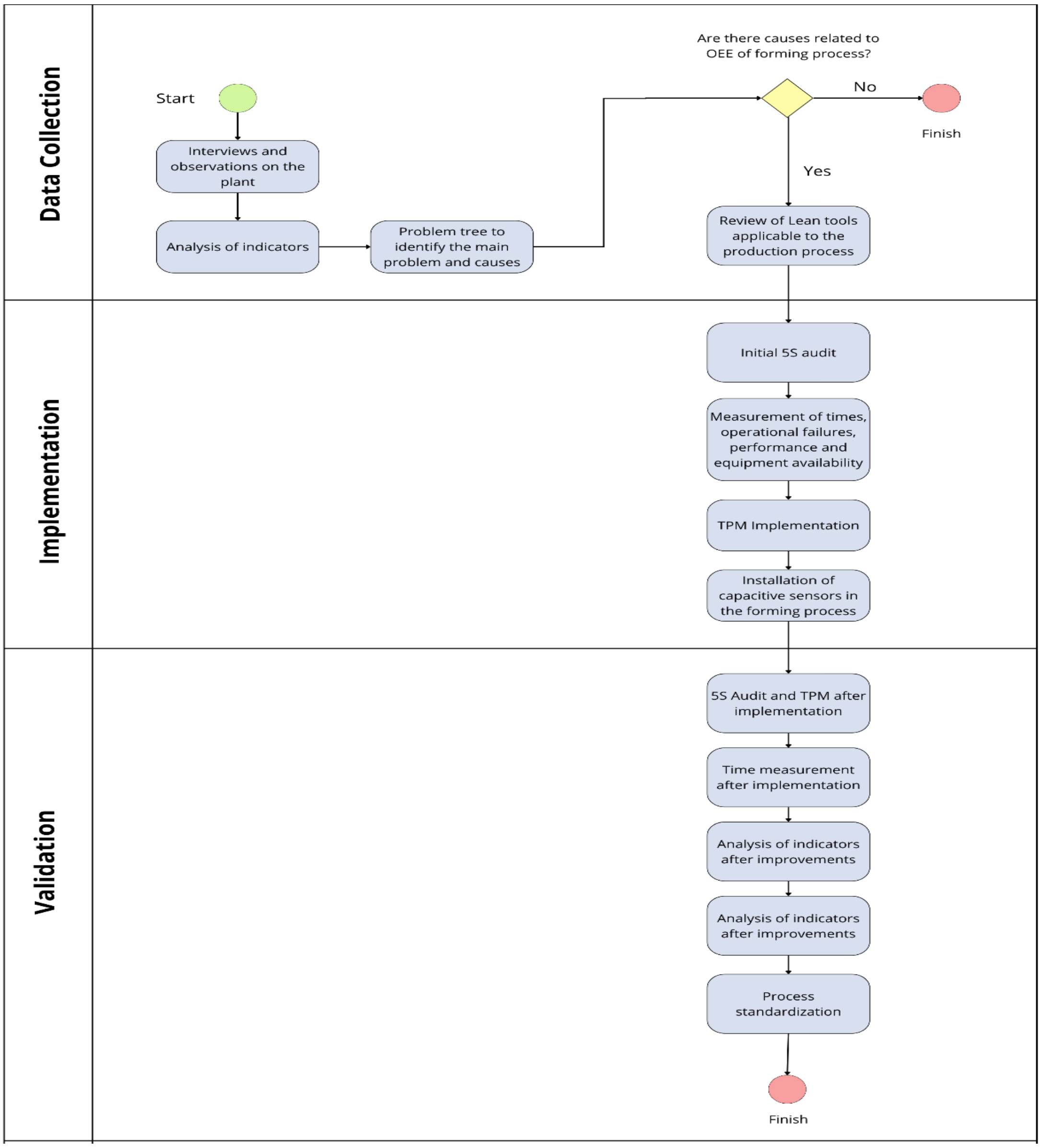

Figure 2. Diagram of the results

4.1. Implementation of 5S and TPM

This section addresses the implementation of the selected lean manufacturing tools, which were applied in the following order: 5s and TPM. In the case study, on the one hand, the company faced problems of order, standardization, cleanliness, classification, and discipline. On the other hand, the company also faced problems of quality, downtime, and downtime. All of these problems prevent the company from achieving its optimal production levels, resulting in sales losses, which harms business profitability.

First, the main process bottleneck was identified. Using a production capacity Table (Table 1) forming production was identified as the limiting process. Process times and forming production indicators were then measured, yielding the following results (Tale 1 and Table 2):

Table 1.Table of times in the forming process

TIME (S)	ACTIVITY	DESCRIPTION		ACTIVITY	TIME (S)
19	2	Set up			
12	1	Smearing of the disc and placement of the protective plastic.	Embutido	3	31
3	4	Apilado de la tapa			
TOTAL FORMING PROCESS PER CAP					53
TOTAL FORMING PROCESS PER CYLINDER					106

Table 2. Principal values before lean implementations

Concept	**Value**	**Unit of measurement**
Minutes per ball in the forming	1.77	min/balloon
Percentage of defectives before TPM in forming	15	%
Minutes per ball before improvements in the entire production process	3.2	min/balloon
Actual production before improvements	215	balls
Availability of the forming machine before TPM	93.8	%
Performance of the forming process before TPM	79.3	%

It was identified that 15% of production is defective, which represents a significant loss of materials and rework, directly affecting the quality of the final product. Furthermore, machine availability is 93.8%, indicating that, although the equipment is operational most of the time, there are still unplanned downtimes that must be addressed. As for throughput, it reached 79.3%, reflecting that the process speed is below ideal, possibly due to downtime or operational delays. These findings allow us to understand the main gaps in the process, which the 5S and TPM tools will focus on.

- 5S Methodology: The implementation of this methodology reduced waste, improved tool location, and established a more orderly work environment at the gas cylinder manufacturing plant. During the initial evaluation, a score of 38 out of 100 was obtained in the 5S audit, which covered the aspects of classification, order, cleanliness, standardization, and discipline. This result reflected 38% compliance, highlighting significant opportunities for improvement in the organization and maintenance of the work area.

- TPM: The initial calculation found that the OEE indicator was 63.2%, primarily affected by the 85% quality score and 55% yield. To improve these values, it was proposed to add capacitive sensors to the machine. These sensors would accurately determine where the disc should be positioned during operation to remove excess burrs, thereby achieving the highest quality score and, consequently, improving yield.

- OEE: 63.2%
- Actual production in cylinders of the forming process: 215 units
- Quality: 85%

5. Results and discussion

Time measurements were taken again three weeks after the 5s implementation, yielding the following results in Table 3:

Table 3. Principal values after lean implementations

Concept	Value	Unit of measurement
Minutes per ball in the forming	1.77	min/balloon
Percentage of defectives before TPM in forming	3	%
Minutes per ball before improvements in the entire production process	3.2	min/balloon
Actual production after improvements	223	balls
Availability of the forming machine before TPM	95	%
Performance of the forming process before TPM	82	%

An evaluation of the 5S methodology was carried out in the area of gas cylinder manufacturing, obtaining compliance with the **87%.** This result demonstrates improvements in the organization and efficiency of the production process. Unnecessary material was eliminated from the stamping and welding areas, optimizing available space. Tools now have defined and marked locations, which has reduced search times. Cleaning was integrated into daily work, with assigned shift managers. Tasks such as component replacement and visual inspection of cylinders were standardized. Furthermore, discipline was reinforced through training and visual monitoring of indicators (Figure 3).

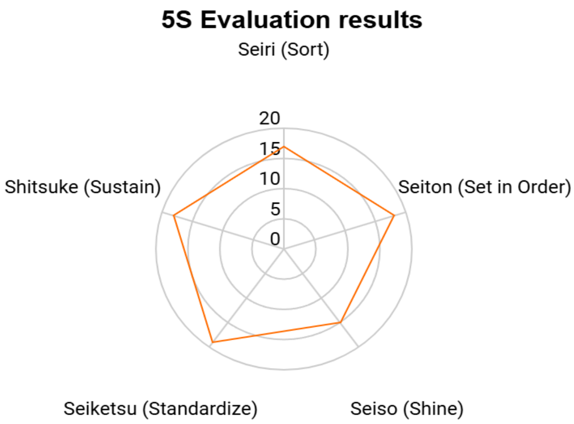

Figure 3. Assessment of the 5's after upgrade

As a complement to the improvements achieved with the 5S methodology, Total Productive Maintenance (TPM) actions were implemented, focusing on ensuring the availability and reliability of the forming machine. An autonomous maintenance schedule was established, in which operators actively participate in inspection, cleaning, and basic lubrication tasks. This strategy reduced unexpected downtime and detected potential failures, thus reducing the frequency of interruptions during the production shift.

Capacitive sensors were also incorporated into the forming station to prevent operator errors in disc placement. These sensors automatically validate the correct position of the material before starting the forming cycle, preventing operational errors and ensuring more precise work. This technological improvement had a direct impact on product quality, raising the quality indicator from 85% to 97%, significantly reducing the percentage of defective units.

As a result of the joint implementation of 5S, TPM, and sensor-based automation, the OEE indicator increased from 63.2% to 75.8%, reflecting a comprehensive improvement in process efficiency.

5.1. Numerical Results

Below are the indicators after TPM and 5S implementations

- OEE: 75.8%
- Quality: 97%
- Production in cylinders of the forming process:: 223

5.2. Graphical Result

Through the application of the tools we were able to obtain the following graphic results (Figure 4 and Figure 5):

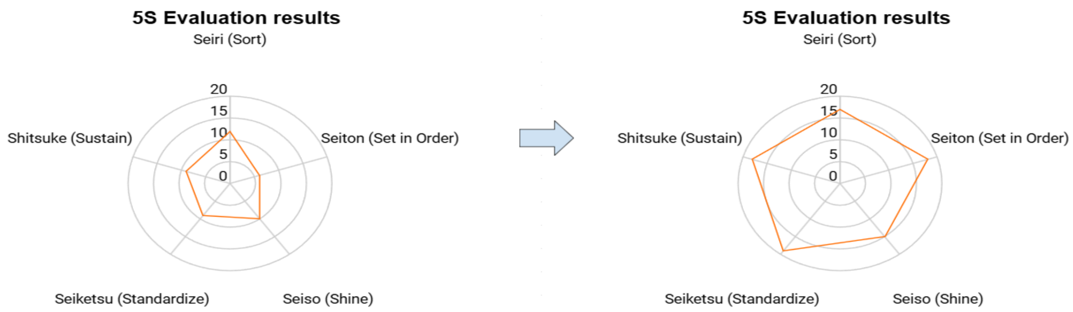

Figure 4. Assessment of the 5's Before and After

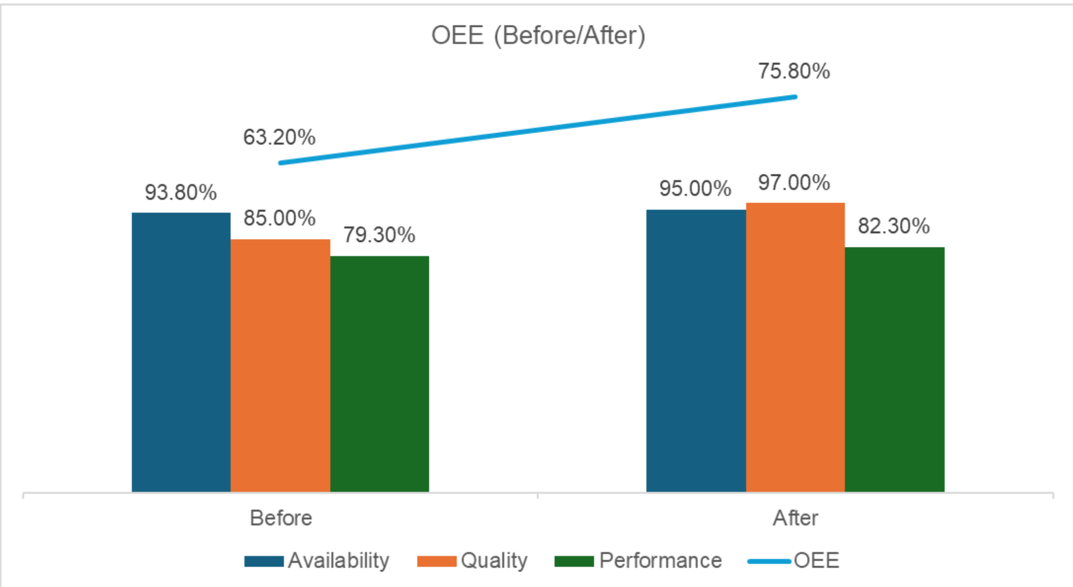

Figure 5. OEE Before and After

5.3 Validation

The proposed model was validated through a three-week pilot test, using the new data obtained after the implementation of the two tools. The indicators were subsequently recalculated. Table 4 shows the results before and after implementation.

Table 4. Comparison of indicators between scenarios

Indicator	Initial Situation	Improved Situation
OEE	63.2%	75.8%
Quality	85%	97%
Balls produced in the forming industry	215	223

Based on the final indicators, it can be stated that the stated objective was achieved, as all indicators showed improvements. Furthermore, continued application of the model within the company would allow for further optimization of results.

6. Conclusion

Based on the results presented in the table above, it is concluded that the implementation of the proposed model in the company analyzed allowed daily production to increase from 215 to 223 cylinders, which demonstrates its effectiveness. Regarding the other indicators, an improvement in process quality was observed, reaching 99% thanks to the incorporation of sensors that reduce human error. Finally, the OEE increased from 63.2% to 75.8%, which indicates a transition from a deficient production level to a more acceptable one.

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