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Improvement of productivity by applying 5S, Work Standardization, Ergonomic Analysis and Poka Yoke in Metalworking Company

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Abstract*– This company manufactures faucets and sanitary ware in Lima, Peru. This study will focus on the faucet product line. This research focuses on studying a company within the metal-mechanic sector that faces productivity issues, negatively impacting its competitiveness. Periodic visits to the company were conducted to collect data. Various tools, such as "5 Whys", Ishikawa diagram and Pareto diagram, were employed to identify the main issues, revealing significant problems such as poorly optimized workstations, low-quality parts, high unproductive times and improper machine usage, among others. The root causes were identified to address them using Lean Manufacturing tools, including 5S, Work Standardization, ergonomic analysis and Poka-Yoke. Improvements were simulated using Arena software, yielding remarkable results, such as a 24% reduction in human errors per quarter, an 11.11% increase in productivity, and a 5% reduction in non-productive times. Finally, the profitability of the proposal was evaluated through a Net Present Value (NPV) of 1,792,845.45 USD, an Internal Rate of Return (IRR) of 66.56%, and a return on investment within less than 1.5 years.

***Keywords*—Metalworking, Productivity, Lean Manufacturing, 5S, Ergonomic Analysis.**

I. INTRODUCTION

A. Background

In 2022, the metalworking sector in Peru contributed 1.2% to the nation's Gross Domestic Product (GDP) and represented 9.5% of the industrial sector's Gross Value Added. Furthermore, in 2021, the Economically Active Population (EAP) employed in this sector increased by 44.7%, amounting to approximately 430,000 jobs [1].

This growth is largely attributed to the country's post-pandemic reactivation, as Peru was one of the nation's hardest hit by the global crisis. For example, in 2021, the national inflation rate reached 6.4% [1], which had a considerable adverse effect across all economic sectors. In addition, the political crisis and the contraction of international demand severely impacted the sector's performance [2].

As a result of this economic regression, countries such as Chile, the United States, and China positioned themselves more effectively in the global market, thereby triggering a snowball effect. With higher financial inflows, these nations saw their industries expand, while Peru, with its limited international market share, lagged behind in terms of competitiveness, solvency, and efficiency.

Currently, international companies are focusing on improving this essential productivity indicator. As such, the emerging trend in the sector revolves around digitalization, robotics, and agile methodologies such as Lean Manufacturing, aiming to increase KPIs (Key Performance Indicators) within firms. Productivity, being the most significant indicator in the metalworking sector [3], has thus become the international benchmark in the industry.

The primary research question is: How can productivity in a metalworking company be increased by applying Lean Manufacturing? Additional questions include: How can non-productive times be minimized? What strategies can be implemented to optimize workstations? How can consistently high-quality parts be produced? among others.

This project is of great importance as it seeks to present a significant improvement model by implementing various Lean tools, with the principal objective of boosting productivity within the company. Additional objectives include identifying the impact of the Lean Manufacturing methodology within the metalworking sector, validating the proposed effectiveness through an economic evaluation with its respective scope and limitations, and, finally, reducing the frequency of human error in the manufacturing process of components by 20% through the implementation of Lean Manufacturing tool

Moreover, the research aims to serve as a reference model for future studies on the benefits of Lean Manufacturing in the metalworking sector.

Regarding the structure of the paper, the first section will present the state of the art, followed by an exploration of the primary problem, which will be specified by each root cause. Next, the components of the proposed solution and the experimental results will be detailed. Finally, an economic evaluation of the project's feasibility will be conducted, followed by a discussion of the key findings and the conclusions of the study.

B. State of the art

Regarding the sources found on the application of Lean Manufacturing in companies within the same or similar sectors, the most commonly used tools are 5S, SLP, JIT, and Poka Yoke. The implementation of 5S has been shown to increase productivity by 5% [4]. It is important to note that other tools, such as SMED and VSM, have various applications, as well as other methodologies designed to address similar issues, including Kaizen, Six Sigma, and Automation. The combined use of these tools promotes improvements in several key indicators, such as productivity, efficiency, reduction of non-productive times, among others. In general, they enhance multiple aspects of the company [5][6].

As for the application of these tools within sector processes, there is evidence of more implementations at the beginning of the process, particularly in transformation and finishing stages. This is where greater variability occurs and where more errors can be made, leading to higher work times and complexity.

The systematic literature review revealed several relevant findings regarding Lean tools in the sector. For example, productivity increased by 8%, while assembly wait times were reduced by 81% [7]. Additionally, there was a 27% reduction in unplanned downtime [4], a 30.5% increase in On-Time Delivery [8], and a 30% reduction in rework [9], among others. Concerning the most recurrent errors, higher incidences were found in non-productive times, late deliveries, low productivity, high production costs, and quality deficiencies in the final part [8]. As for non-productive times, they were primarily linked to delays in obtaining the necessary tools to handle the part or in transportation from one location to another [7]. Regarding low productivity and part quality, a strong correlation with ergonomics was found, as improper workstation design directly impacts worker performance and thus productivity [10].

There are implementation barriers, particularly in relation to the digitalization and automation of processes, which are key aspects of both Lean Manufacturing and Industry 4.0. People often resist change, as they feel comfortable with repetitive tasks. Ultimately, the trend is towards a blend of traditional and modern approaches for the time being [11].

II. PROBLEM

The case study for this work is a large company in the metal-mechanical sector located in Lima, Peru. The company operates two production lines: faucets and sanitary ware, with the analysis focusing on the first line. In 2023, it produced 966,700 units, achieving an operating income of $31,415,845.61 and a service level of 98.47%. When comparing the company to the international sector, significant differences emerge, highlighting the company's primary weakness: productivity. While the sector average is 33 units per machine-hour, the company exhibits an efficiency rate of 94%, a rework rate of 25.4%, a human error frequency of 20 errors per quarter, unproductive time amounting to 200 minutes, and an absenteeism rate of 5%.

Indicators	Sector	Company under study	Units	Percentage difference
Total productivity	33	18	Units / MH	**-45.45%**
Efficiency	94%	81	Percentage	**-13.83%**
Reprocessed parts percentage	25.4%	28.4%	Percentage	**+11.81%**
Human error frequency in polishing	20	33	Errors/trimester	**+65.00%**
Total unproductive time	200	280	Minutes / trimester	**+40.00%**
Absenteeism percentage	5%	8.72%	Percentage	**+74.40%**

Fig. 1 Comparative Analysis between Company and Sector

This issue results in an economic impact of $685,932.63 annually, representing nearly 3% of the company's annual revenue.

Why focus on productivity rather than other indicators?

Productivity is the key metric for assessing the sector's competitiveness on an international scale. When the sector demonstrates high productivity, it indicates that all its components are functioning in harmony. Conversely, low productivity necessitates identifying and addressing deficiencies, particularly in a sector like metal-mechanics, which significantly contributes to GDP. As a large company with adequate production capacity, it is essential to optimize operations to produce components using the least amount of resources possible.

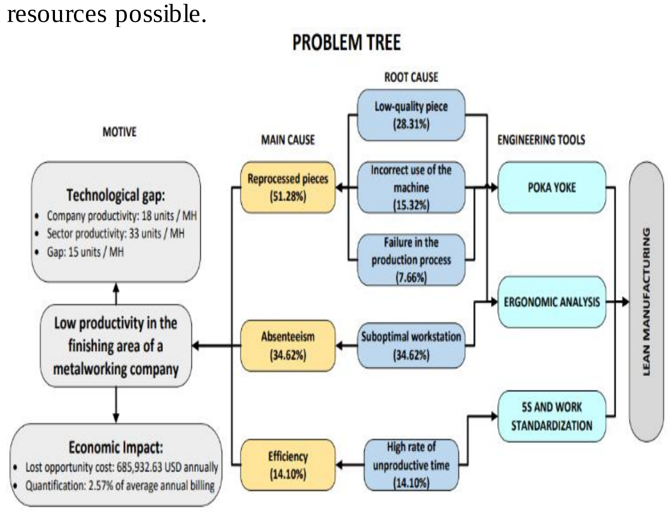

Fig. 2 Problem Tree

After defining the problem, periodic visits to the production plant were conducted to collect data and identify the causes of low productivity within the company. As illustrated in the problem tree in Fig. 2, the root causes of low productivity were identified as a combination of low efficiency, high absenteeism rates, and a high rework rate for components. To identify the root cause with the greatest impact, a Pareto diagram was utilized, as shown in Fig. 3.

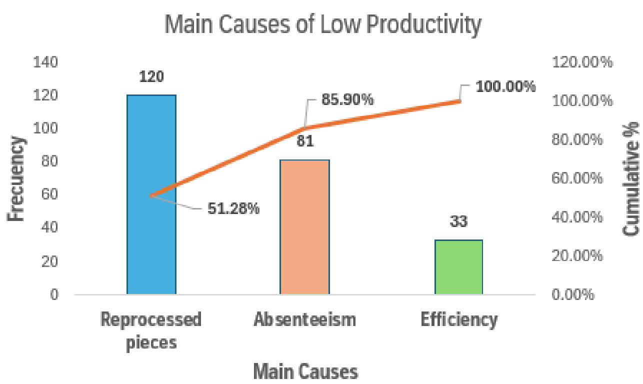

Fig. 3 Pareto Chart

A. Reprocessed piece

Given the company's high-quality standards, components must meet impeccable criteria. However, since the process involves manual handling, operators may make errors due to the lack of process standardization. Each operator performs tasks according to their individual interpretation of how they should be done. This leads to defects in components or incidents related to improper machine usage, resulting in multiple rework cycles until the required specifications are met.

B. Absenteeism

The polishing and chrome-plating processes in the company are manual and repetitive activities that place a significant physical burden on workers. The company employs fixed workstations, where the operator must adapt to the station rather than the station adapting to the operator. Consequently, the company tends to hire individuals of average height to ensure they can work in an ergonomically favorable posture.

C. Efficiency

Efficiency in this context involves maximizing production while minimizing waste, costs, and downtime. In this sector, it is measured by the amount of time lost due to operator errors during their tasks. Common issues in polishing include uneven polishing, incorrect surface thickness, and over-polishing. In chrome plating, common errors involve inadequate surface preparation, incorrect immersion times, and improper quantities of additives.
After outlining the entire problem, the proposed solution is presented, targeting the root causes using Lean Manufacturing tools, followed by a simulation in Arena software. Once the project's feasibility is demonstrated, its economic viability will be assessed.

III. Methodology and Innovative Proposal

The root causes of inefficiencies in the chrome-plating process were addressed using Lean Manufacturing tools tailored to the identified operational challenges. The 5S methodology was implemented to enhance workplace organization, reducing unnecessary waste and improving cleanliness, which facilitates efficiency and reduces downtime by approximately 15%, as evidenced in previous applications. Work Standardization was chosen to ensure consistency and reduce variability in operational tasks, particularly in the mixing and chrome-plating stages. By introducing standardized procedures, the study aimed to improve task efficiency and minimize human errors. Ergonomic Analysis was applied to address risks associated with repetitive tasks, enhancing worker comfort and reducing absenteeism. This improvement contributed to increased operator satisfaction and overall team efficiency.

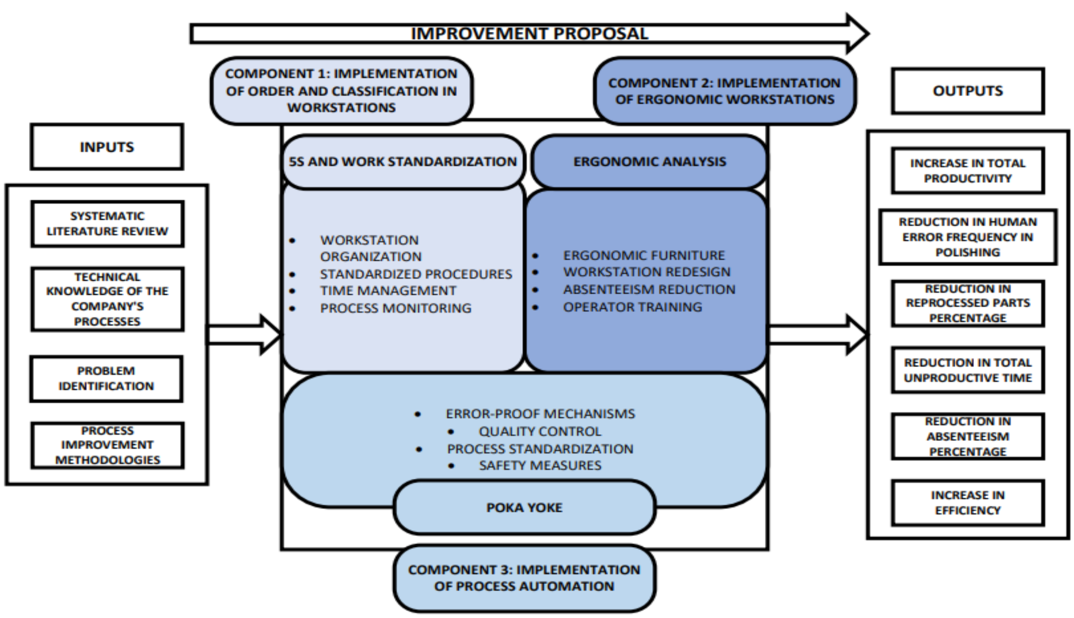

Fig. 4 Proposed Model

Finally, Poka-Yoke systems were incorporated to prevent human errors during critical stages of the process. Similar implementations in the industry have shown a reduction in defect rates by up to 30%, underscoring its effectiveness in achieving high-quality standards.

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

In formula (1) to determine the sample size for the bronze faucets, the population "N" was calculated as 63.88% of the total production capacity, equivalent to 7,985 units. The confidence level selected was 95%, giving a security value "Z" of 1.96. The probabilities "p" and *"q"* were set at 50% each to ensure a conservative estimate, and the maximum allowable error "e" was set at 5%. Using these parameters, the formula yielded a minimum sample size of 367 bronze faucets. The study variables considered include setup time, total production time, error rates, and defect percentages, which will form the basis for the indicators used to assess and quantify the improvements proposed in the study.

A. *Component 1: 5S with Work Standardization*

The implementation of 5S and Work Standardization in the polishing area aimed to optimize operations by improving workspace organization and reducing unnecessary movements. After analyzing workflows and consulting operators, a mobile cart was introduced to centralize frequently used tools and materials, ensuring they were easily accessible. This innovation streamlined processes and reduced delays, while operator training reinforced proper organization and maintenance, fostering a culture of efficiency and standardization in the workplace. This approach highlighted the practical application of Lean Manufacturing tools to improve operational performance, as seen in Fig. 5.

Fig. 5 Mobile cars for the polishing area

These carts are designed to centralize tools and materials, minimizing unproductive movements and optimizing workflows. The proposed objective is to achieve a 5% reduction in total unproductive time per trimester, aiming to streamline operations and place this indicator within optimal efficiency parameters. Additionally, the initiative seeks to increase overall efficiency by 4%, enhancing the organization and standardization of processes. This approach aligns with Lean principles and emphasizes measurable improvements in operational performance, as seen in Fig. 6.

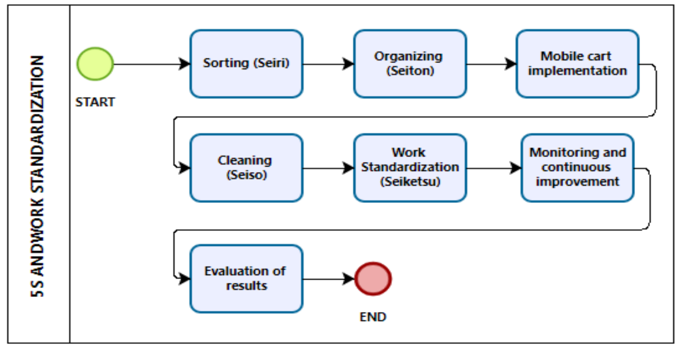

Fig. 6 5S and Work Standardization Flowchart

B. *Component 2: Ergonomic Analysis*

The implementation of Ergonomic Analysis in the polishing area was aimed at improving operator comfort and reducing physical strain during repetitive tasks. Following a detailed assessment of workstations and operator feedback, ergonomic chairs were introduced at polishing stations to provide proper support and alignment. These chairs were selected based on anthropometric data and adjusted to the height and posture requirements of the operators, ensuring an optimal working position. This innovation reduced fatigue and the risk of musculoskeletal injuries, fostering a safer and more efficient work environment. The integration of ergonomic design principles highlighted the importance of aligning workspace tools and furniture with human factors to enhance productivity and worker well-being, as seen in Fig. 7.

Fig. 7 Work chair for polishing

In this stage, suggestions were proposed to improve the ergonomic setup of polishing workstations by introducing ergonomic chairs. The process included defining new ergonomic standards, reducing absenteeism rates, and minimizing the percentage of reprocessed parts. Once these objectives were established, the expected improvements were set to decrease absenteeism to 7.50% and lower reprocessed parts to 26%. Additionally, procedures for monitoring absenteeism and quality metrics were updated, while maintenance activities for ergonomic chairs were outlined to sustain these benefits. This approach was structured into a flowchart to guide implementation and ensure long-term results, as seen in Fig. 8.

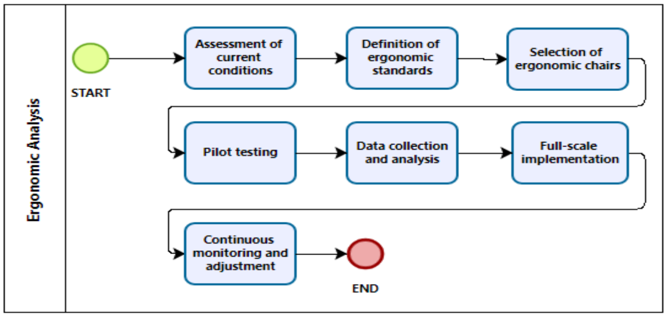

Fig. 8 Ergonomic Analysis Flowchart

C. Component 3: Poka Yoke

The implementation of Poka-Yoke in the chrome-plating area aimed to improve operational consistency and reduce errors during the process. After identifying inefficiencies and risks associated with manual handling, a semi-automated monorail system was introduced. This system facilitated the movement of materials and parts between stages, minimizing human intervention and ensuring a standardized workflow. The monorail reduced the likelihood of errors in positioning and timing, which were common in the manual process, while also improving safety and ergonomics for operators. This innovation highlights the effectiveness of Poka-Yoke principles in reducing variability and enhancing the reliability of the chrome-plating process, as seen in Fig. 9.

Fig. 9 Semi-automated monorail for chrome plating

In this stage, proposals were made to improve the chrome-plating process by implementing a semi-automated monorail system as a Poka Yoke solution to address human errors. The initiative aims to reduce the frequency of human errors in polishing to a target of 25 errors per quarter, representing a significant improvement in process consistency and quality. To support the achievement of this goal, operational parameters for the monorail system will be defined, and staff training will ensure proper usage. This structured approach was visualized in a flowchart to guide implementation and long-term operational success, as seen in Fig. 10.

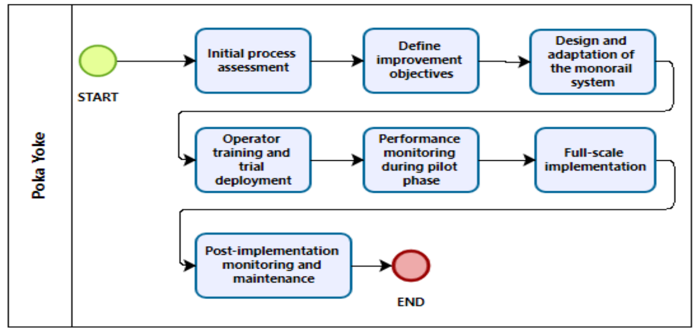

Fig. 10 Poka Yoke Flowchart

The following table presents the key performance indicators (KPIs) for each improvement tool implemented in the project. The "As Is" column reflects the baseline values prior to the implementation of Lean Manufacturing tools, while the "To Be" column shows the expected improvements after applying methodologies such as Lean Philosophy, Poka Yoke, Ergonomic Analysis, and 5S and Work Standardization. These indicators highlight the targeted enhancements in productivity, error reduction, absenteeism, reprocessed parts, unproductive time, and overall efficiency across the chrome-plating and polishing processes. as seen in Table 1.

TABLE I
EXPECTED OUTCOMES FOR THE IMPROVEMENT PROPOSAL

Component	Indicator	Unit	As Is	To Be
Lean philosophy	Total productivity	Units/M-H	18	20
Poka Yoke	Human error frequency in polishing	Errors/trimester	33	25
Ergonomic analysis	Absenteeism percentage	Percentage	8.72%	7.50%
	Reprocessed parts percentage	Percentage	28.4%	26.0%
5S and Work Standardization	Total unproductive time	Minutes / trimester	280	266
	Efficiency	Percentage	81%	85%

The three improvement proposals were evaluated on the Arena model, the model simulates the polishing and chrome-plating processes within the finishing area, as seen in the Fig. 14. These processes were analyzed to identify inefficiencies and test proposed improvements, focusing on optimizing workflow, reducing errors, and increasing overall productivity. The model includes record counts to analyze key performance indicators (KPIs), enabling a detailed evaluation of process improvements and their impact on operational efficiency.

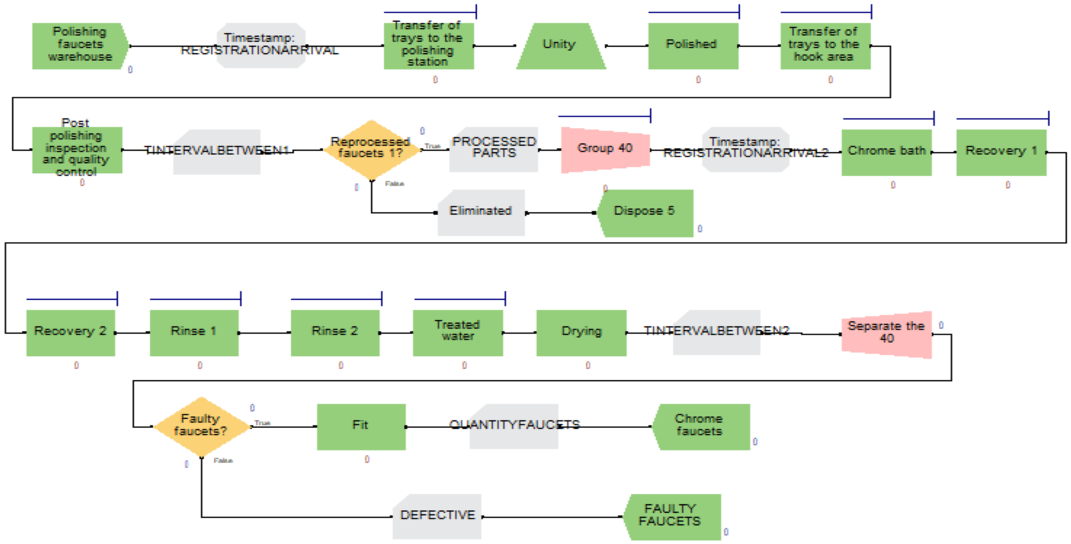

Fig. 11 Arena Model

IV. Results

A. Simulation Results

After the simulation in Arena, results were obtained for the defined indicators, which were analyzed to evaluate the impact of the proposed improvements. The selected indicators include Productivity, Efficiency, Percentage of Reprocessed Pieces, Frequency of Human Errors in the Polishing Area, and Total Unproductive Time.

Each indicator was compared against the target goals set for the process, providing a comprehensive assessment of operational performance enhancements. These results demonstrate the effectiveness of the Lean Manufacturing tools and strategies implemented in optimizing the company's key processes. In Fig. 11 shows the results obtained in the simulation.

Indicator	Record Count in Arena	Achieved
Total productivity	RECORDPRODUCTIVITY	21.9 Units / M-H
Efficiency	$\frac{\text{FAUCETS.NumberOut}}{\text{FAUCETS.NumberIn}} * 100$	87.49%
Reprocessed parts percentage	$\left(\frac{\text{REPROCESSEDFAUCETS} + \text{RECHROMEFAUCETS}}{\text{FAUCETS.NumberIn}}\right) * 100$	23.25%
Human error frequency in polishing	REPROCESSEDPARTS	25 Errors/trimester
Total unproductive time	FAUCETS.WaitTime	254.23 minutes

Fig. 12 Results obtained in Arena software

In the case of the productivity indicator measured in units per Men Hour, the initial value was 18 units/MH, with a target set at 20 units/MH. The simulation results exceeded expectations, achieving a value of 21.9 units/MH, representing an improvement of 21.67% compared to the initial state, as seen in Fig. 13.

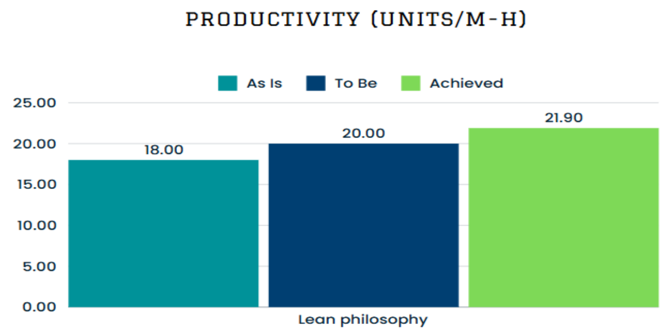

Fig. 13 Productivity Indicator

In the indicator Human Error Frequency in Polishing, the initial value was 33 errors per trimester (As Is), with a target set at 25 errors per quarter (To Be). The implementation results matched the target, achieving a value of 25 errors per quarter, representing a reduction of 24.24% compared to the initial state, as seen in Fig. 14.

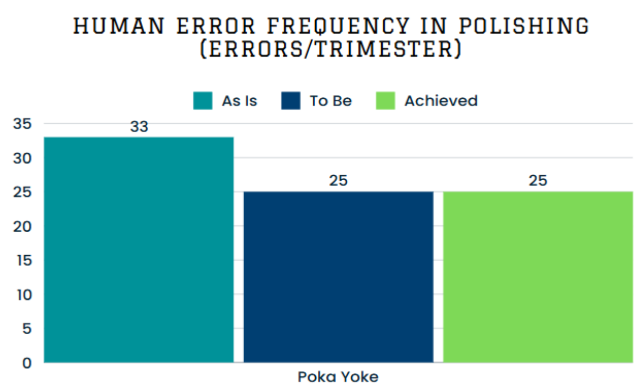

Fig. 14 Human error frequency in polishing Indicator

For the indicator Reprocessed Parts Percentage, the initial value was 28.40% (As Is), with a target set at 26% (To Be). The implementation results exceeded expectations, achieving a value of 23.25%, representing a reduction of 18.14% compared to the initial state, as seen in Fig. 15.

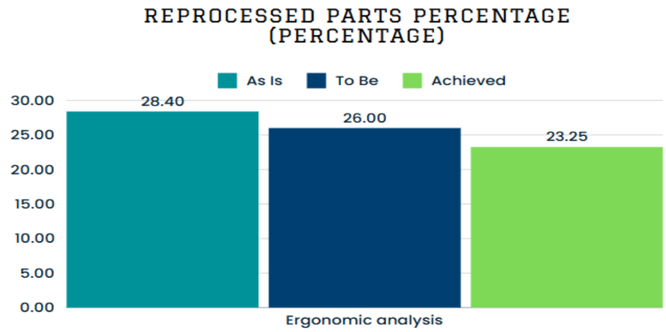

Fig. 15 Reprocessed parts percentage Indicator

For the indicator Total Unproductive Time, the initial value was 280 minutes per quarter (As Is), with a target set at 266 minutes per trimester (To Be). The implementation results exceeded expectations, achieving a value of 254.23 minutes per trimester, representing a reduction of 9.19% compared to the initial state, as seen in Fig. 16.

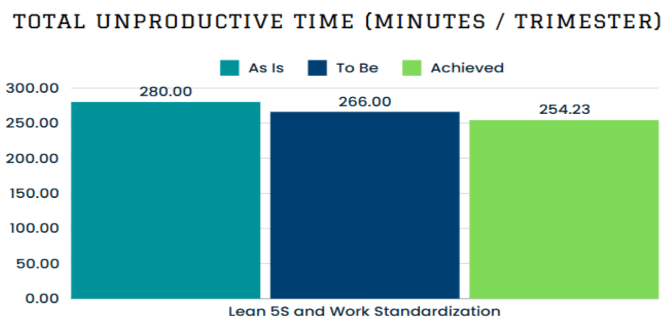

Fig. 16 Total unproductive time Indicator

Finally, for the indicator Efficiency, the initial value was 81% (As Is), with a target set at 85% (To Be). The implementation results exceeded expectations, achieving a value of 87.48%, representing an improvement of 8% compared to the initial state, as seen in Fig. 17.

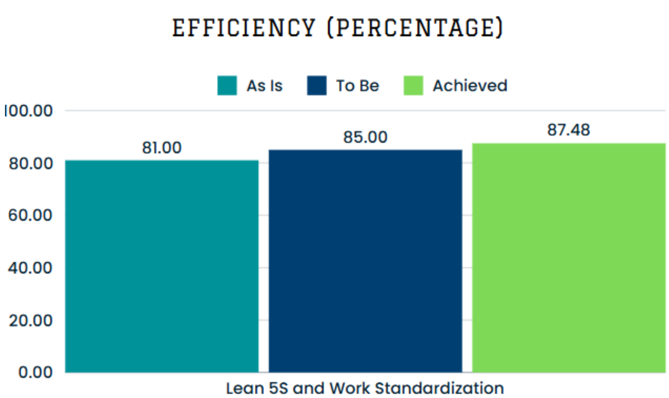

Fig. 17 Efficiency Indicator

B. *Field Results*

The indicator Absenteeism Percentage was analyzed based on the medical leave records in the finishing area of the company. This metric reflects the proportion of absenteeism due to health-related reasons, providing critical insights into the working conditions and ergonomic challenges faced by employees. By addressing the root causes through targeted ergonomic interventions, significant improvements were achieved, directly impacting workforce availability and operational efficiency.

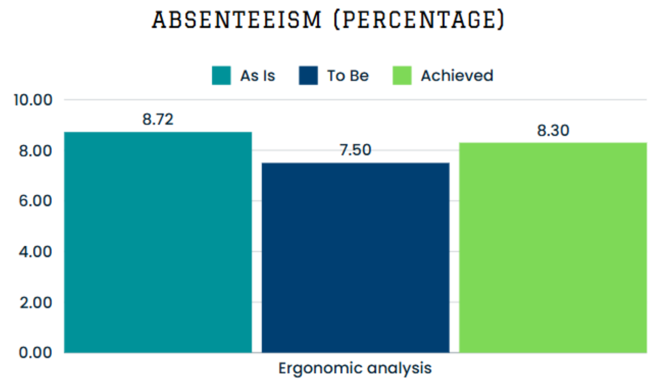

Fig. 18 Absenteeism percentage Indicator

As seen in the Fig. 18, for the indicator Absenteeism Percentage, the initial value was 8.72% (As Is), with a target set at 7.50% (To Be). The implementation results showed a value of 8.30%, representing a reduction of 0.42 percentage points compared to the initial state. This improvement highlights the positive impact of ergonomic adjustments.

C. *Economic Evaluation*

In the economic evaluation of the project, a detailed analysis was conducted to determine the required investment of $1,110,772.63 for implementing the proposed solutions. It is important to highlight that this investment will be entirely financed with the company's internal funds, eliminating the need for external financing. This approach ensures greater control over financial resources and reduces dependency on external creditors, aligning with the company's strategic financial planning.

For the analysis of financial indicators, the Opportunity Cost of Capital (COK) was calculated with the financial asset valuation model (CAPM), which was calculated with the following formula:

$$COK = Rf + B \cdot (Rm - Rf) + Rp \qquad (2)$$

In formula (2), "Rf" represents the Risk-Free Rate, which in emerging markets like Peru is often benchmarked using the 10-year U.S. Treasury bond yield. For 2024, the average yield from January to September was 4.17%. "β" (Beta) measures the volatility of the sector compared to the overall market. For the metalworking industry in 2024, Beta is estimated at 1.2, indicating higher volatility than the general market. The Expected Market Return (Rm) for Peru in emerging markets is 9%, based on historical market projections. Additionally, the Country Risk Premium (Rp) accounts for Peru's status as an emerging market, estimated at 4% for 2024. With these values the annual COK of the project is 12.71%.

Using these inputs, the project's cost of capital (COK) was calculated to evaluate the profitability indicators for the incremental cash flow over a 5-year project horizon, as illustrated in Table 2.

TABLE 2
RESULTS OF ECONOMIC INDICATORS

Economic Evaluation Overview	Value
Net Present Value (NPV)	1,792,845.45 USD
Internal Rate of Return (IRR)	66.56%
Cost-Benefit Analysis	1.43 USD
Payback Period	1.41 years

From the results, it can be concluded that the project is economically viable because the NPV is positive, the IRR exceeds the COK value (13.81%), the Benefit/Cost ratio is greater than 1, and the payback period is shorter than the project horizon (5 years).

D. Sensitivity Analysis

To perform the sensitivity analysis for the improvement proposal, the @Risk tool was utilized. This tool enables the assessment of how favorable or unfavorable scenarios can influence the project's economic indicators. For this analysis, three key scenarios were considered:

- Variation in selling price: The selling price was analyzed under three conditions: a pessimistic scenario with a 15% decrease, resulting in an NPV of -3,277,138.18 USD; a current scenario with no variation, yielding an NPV of 1,575,800.13 USD; and an optimistic scenario with a 15% increase, leading to an NPV of 6,671,098.47 USD.
- Variation in sales: Sales was examined under a pessimistic scenario with a 20% decrease, resulting in an NPV of 263,386.31 USD; a current scenario with no change, achieving an NPV of 1,575,800.13 USD; and an optimistic scenario with a 20% increase, yielding an NPV of 3,677,219.83 USD.
- Variation in cost of sales: The cost of sales was assessed with a pessimistic scenario where costs increased by 30%, leading to an NPV of -299,364.86 USD; a current scenario with no variation, resulting in an NPV of 1,575,800.13 USD; and an optimistic scenario where costs decreased by 30%, yielding an NPV of 3,215,148.42 USD.

Additionally, a combined scenario encompassing all these variables was considered. In the pessimistic case, the NPV was -3,313,116.73 USD, while in the optimistic case, it reached 13,563,466.72 USD. As illustrated in the results, the project's profitability is highly sensitive to variations in these key factors, as seen in the Fig. 19.

Variable	Type	Probability	Variation	NPV
Selling price	Pessimistic	15%	-15%	$ -3,277,138.18
	Moderate	50%	0	$ 1,575,800.13
	Optimistic	35%	15%	$ 6,671,098.47
Sales	Pessimistic	15%	-20%	$ 263,386.31
	Moderate	50%	0	$ 1,575,800.13
	Optimistic	35%	20%	$ 3,677,219.83
Cost of sales	Pessimistic	35%	30%	$ -299,364.86
	Moderate	50%	0	$ 1,575,800.13
	Optimistic	15%	-30%	$ 3,215,148.42
General	Pessimistic	15%	-	$ -3,313,116.73
	Moderate	50%	-	$ 1,575,800.13
	Optimistic	35%	-	$ 13,563,466.72

Fig. 19 Sensitivity Analysis

The Net Present Value (NPV) was chosen as the primary metric for assessing the project's economic feasibility. In the worst-case scenario (pessimistic), where selling prices decrease by 15%, the NPV is -3,277,138.18 USD, highlighting the project's vulnerability to price reductions. In the best-case scenario (optimistic), with a 15% increase in selling prices, the NPV reaches 6,671,098.47 USD, demonstrating the significant profitability potential under favourable conditions. This underscores the importance of selling price as a critical variable for the project's success.

V. Discussion

In general terms, the lean tools applied as a proposed solution have greatly contributed to achieving the main objective of improvement in the company analyzed. The initial goal was to increase from 18 to 20 units per man-hour, similar to the improvement achieved by Jara, which was 10% [6]. In the Arena simulation, a result of 21.9 units per man-hour was obtained, resulting in an increase of 11.11%.

Regarding the first component, which is the implementation of 5S with Work Standardization, mobile carts with the most commonly used tools and materials were introduced. Data collection was conducted over a period of 4 months following the implementation. The aim was to reduce total unproductive time from 280 to 266 minutes per quarter, as Del Rosario's improvement achieved a reduction of 7%, while ours aimed for 5% [7]. Additionally, this improvement sought to increase efficiency by 4%, moving from 81% to 85%; however, it was increased to 87.48%, though it did not reach the increment achieved by Del Rosario, which was 10% [7]. An investment of 5,984.74 USD was made.

For the second component, which involves ergonomic analysis, data was collected quantitatively and qualitatively, followed by the implementation of a chair. Data collection was carried out over a period of 4 months post-implementation. The goal was to reduce absenteeism from 8.72% to 7.5%, implying a reduction of around 2%, as Voordt achieved a reduction of 3%; however, only a 0.42% reduction was achieved [12]. Nonetheless, this improvement also aimed at reducing reprocessed pieces from 28.4% to 26%, following Del Rosario's approach, which achieved a 12% reduction in this indicator [7]. Similar results were reported by Murga-Vasquez et al., who implemented TPM and Kaizen tools to reduce rework in a metalworking company, achieving notable process improvements [9]. After the simulation, a reduction of 5.15% was achieved, which is a good indicator, given that large-scale production amplifies the impact. An investment of 6,229.74 USD was made.

The third and final component is Poka Yoke, where a semi-automated monorail system was chosen. Data collection was conducted over a period of 6 months following the implementation. A reduction of 24.24% was expected, decreasing errors from 33 to 25 per quarter, following Arbieto's work, which achieved a 23% reduction [5]. After the Arena simulation, the expected result was achieved. An investment of 1,098,558.42 USD was made.

From an economic perspective, the project's financial indicators confirmed its viability, with an NPV of 1,792,845.45 USD, an IRR of 66.56%, and a payback period of less than 1.5 years. The sensitivity analysis reinforced the robustness of the proposal, showing minimal risk from variations in costs or sales expenses. These findings highlight the dual benefit of operational enhancements and economic sustainability, demonstrating that Lean tools can deliver tangible financial returns alongside process improvements.

Finally, the most notable limitation during the project was the lack of knowledge and commitment from workers toward the new implementations, as they felt they were being replaced. Additionally, there were difficulties in simulating the performance of the semi-automated monorail system. For this reason, it is recommended for future research to provide a preliminary talk on what is being improved and how it will be implemented, rather than proceeding without their knowledge, and to explore different simulation tools in case machinery of this scale is to be implemented.

VI. CONCLUSIONS

The application of Lean Manufacturing tools, including 5S, Work Standardization, Ergonomic Analysis, and Poka-Yoke, successfully improved productivity in the metalworking company, increasing output from 18 to 21.9 units per man-hour, a 21.67% improvement.

These tools addressed critical inefficiencies, such as high non-productive times, frequent human errors, and ergonomic deficiencies, showcasing their impact on enhancing operational consistency and competitiveness in the metalworking sector.

The economic validation confirmed the feasibility and sustainability of the project, with a Net Present Value (NPV) of $1,792,845.45 USD, an Internal Rate of Return (IRR) of 66.56%, and a payback period of less than 1.5 years. Furthermore, human errors were reduced by 24.24%, achieving the target of decreasing errors in the polishing process to 25 per quarter.

The results of indicators demonstrate the replicable potential of Lean tools to improve operational efficiency, workplace conditions, and economic performance, emphasizing the importance of process optimization and worker well-being for sustainable growth in the industry.

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