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Occupational Risk Prevention Model in the Production Area of a Peruvian Metalworking SME to Reduce Workplace Accidents

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Abstract

This study addresses the high incidence of workplace accidents in a Peruvian metalworking SME, attributed to the lack of order and cleanliness at the workstation and non-compliance with safety standards. To reduce workplace accidents, the research focused on a pilot test in the welding area, applying good Occupational Safety and Health (OSH) practices and implementing the 5S methodology following the PDCA continuous improvement cycle. The results show a 100% reduction in monthly workplace accidents and a significant increase of 92% in compliance with safety standards, as well as 94% compliance in the 5S Checklist. These improvements also reduced risk levels, tool search times, and enhanced discipline regarding workstation cleanliness. These findings validate the effectiveness of the implemented approach and suggest potential scalability to the entire production area.

Keywords
Safety, Workplace accidents, Risk, Metalworking, Productivity

1. Introduction

The metalworking sector is essential to the Peruvian economy. It is based on the transformation of metals to produce machine parts and tools used across various industries, from construction to mining. In 2021, this industry accounted for 10.9% of the Gross Value Added (GVA) of the manufacturing sector and 1.4% of the national Gross Domestic Product (GDP), valued at 552.56 billion soles (Produce 2022).

The metalworking industry plays a key role in employment generation in Peru. It represents 22.9% of the Economically Active Population (EAP) within the manufacturing sector and 2.1% of national employment. In 2021, the metalworking industry generated 399,626 jobs, a 22.7% increase compared to the previous year. In 2022, the industry continued to grow by 10.5%, mainly due to the increased demand for metalworking goods and services from the mining and construction sectors, which were in expansion. Additionally, metalworking exports reached US$ 767 million (FOB), an 18.9% increase (Produce 2022).

Although the Peruvian metalworking sector has experienced growth in recent years, there are still areas for improvement. Among these, high workplace accident rates and low productivity levels stand out. The most urgent issue is worker safety, as workplace accidents can cause serious injuries or even death.

In December 2022, a total of 2,453 notifications of workplace accidents, dangerous incidents, and occupational diseases were recorded in Peru. Of these, 97.15% corresponded to non-fatal accidents, 1.02% to fatal accidents, 1.79% to dangerous incidents, and 0.04% to occupational diseases (Ministry of Labor and Employment Promotion 2022). The economic activity with the highest number of notifications was manufacturing, accounting for 24.96% of the total, followed by real estate, business, and rental activities with 16.72%, and commerce with 11.87% (MTPE 2022). These figures show that workplace accidents remain a major problem in Peru and highlight the need for effective safety measures to protect workers.

Workplace accidents are a global issue that negatively impacts health, productivity, and business performance. According to the International Labour Organization (ILO), more than 317 million workplace accidents occurred worldwide in 2021. These accidents have devastating effects on workers, their families, and the companies themselves, resulting in lost productivity, income, and reputation. The economic cost of workplace accidents is enormous, with poor safety and health practices estimated to cost the global economy around 4% of annual GDP (ILO 2017).

1.1 Objectives

This study aims to implement an occupational risk prevention model in the production area of a Peruvian metalworking SME to reduce workplace accidents. To achieve this objective, the study focuses on: (1) reducing workplace accidents and risk levels through the identification and elimination of substandard conditions using good occupational safety and health (OHS) practices; (2) improving workplace productivity through the implementation of 5S, evaluated by tool search time reduction and 5S compliance levels; (3) assessing the economic feasibility of the proposed model using financial indicators such as Net Present Value, Internal Rate of Return, benefit/cost ratio, and payback period; and (4) evaluating the effectiveness and scalability of the model for full implementation in the production area.

2. Literature Review

For the selection of academic sources, the PRISMA method was applied, which made it possible to identify the most relevant studies for this research in three central areas: Occupational Safety and Health (OSH), productivity, and the 5S methodology. This method facilitated the identification of studies with solid empirical evidence and applicable to the context of a Peruvian metalworking SME.

The comparative analysis of the selected sources reveals clear consistencies regarding the effectiveness of Occupational Health and Safety Management Systems (OHSMS). The literature highlights that models based on diagnostics, operational controls, and continuous monitoring significantly reduce accident frequency and strengthen preventive culture in industrial organizations (Céspedes Tuero 2022). Likewise, various studies confirm that OHSMS not only improves safety but also increases operational efficiency and sustainability by standardizing critical processes (Anaya 2017).

Similarly, the review shows that the 5S methodology is an effective tool for eliminating substandard conditions, improving order, reducing waste, and promoting visual control in metalworking environments. These improvements translate into greater operational productivity and reduced workplace risks when implemented in a disciplined and sustained manner (Ramdass 2015). Other studies show that the comprehensive application of 5S generates rapid improvements in organization and safety, facilitating its adoption in small and medium-sized enterprises (Rodrigues et al. 2020).

The literature review also highlights the relevance of integrating Lean approaches with OSH tools, as this combination simultaneously enhances efficiency and safety, particularly in intensive manufacturing processes (Prashar 2018). This alignment of findings supports the selection of both tools as a solution to address the identified problem.

A key aspect identified in this review is the role of pilot tests as an essential preliminary stage before extending an intervention to an entire production area. In Lean models, pilots allow technical validation of proposals, early results, and reduced resistance to change (Rodrigues et al. 2020). Likewise, they enable observation of the system's real response under controlled conditions, ensuring the sustainability of the solution before scaling it up (Prashar, 2018).

In the field of occupational safety, it is recommended to begin interventions in pilot units to validate controls and adjust procedures before expansion, thereby improving preventive effectiveness (Nadeem 2022).

Based on the above, the following research question was formulated: How does the application of an occupational risk prevention model impact in the reduction of workplace accidents in a Peruvian metalworking SME?

2.1 5S Implementation

The reviewed literature confirms that the 5S methodology is one of the most effective practices for organizing and structuring workspaces, especially in industrial environments where material accumulation, lack of standardization, and limited tool visibility increase operational risks. Under this approach, it is demonstrated that the proper implementation of 5S requires not only applying the five principles but also ensuring employee participation through a committee responsible for directing and supervising each phase of the process. As Ramdass states, disciplined implementation of this methodology "reduces variations, improves tool accessibility, and facilitates visual control, generating direct improvements in safety and productivity" (Ramdass 2015).

Likewise, various studies agree that conducting an initial diagnosis through a structured checklist is essential to define an accurate baseline, necessary for comparing progress and validating the real impact of the intervention. Similarly, Pérez emphasizes that the methodology "not only organizes the workspace, but also establishes standardized routines that reduce non-productive times and strengthen organizational culture" (Pérez 2017). Furthermore, other studies highlight that the incorporation of visual controls facilitates the adoption of new practices and reinforces operational discipline throughout the implementation process (Kanamori et al. 2016).

Within this framework, the proposal of the present study replicates the best practices identified in the literature review: initial diagnosis, training, leadership by the 5S committee, visual controls, and final auditing. This integrated set of actions not only transforms the physical order of the workspace but also consolidates a safer operational culture oriented toward continuous improvement.

2.2 Implementation of good Occupational Health and Safety Practices

The literature on Occupational Safety and Health (OSH) indicates that the implementation of good practices constitutes a systematic process that begins with the characterization of the organization and the identification of risks present in its operations. According to García, "the initial characterization of the work environment is essential to define intervention priorities and ensure the effectiveness of the preventive system" (García 2010). This diagnosis serves as the starting point for evaluating compliance with Law 29783, establishing baselines, and identifying gaps within the OSH Management System (OHSMS).

Furthermore, studies focused on the application of the OHSMS agree that the IPERC matrix is a central tool for classifying hazards, quantifying risks, and defining control measures that are aligned with the reality of each work area (Anaya 2017). Its use enables the planning of preventive actions aimed at eliminating hazards, implementing engineering controls, regulating processes through procedures, and reinforcing the proper use of personal protective equipment.

It is also highlighted that the effectiveness of an OHSMS depends on continuous training, monitoring of preventive performance, and tracking indicators such as accident rates, regulatory compliance, and risk levels. Céspedes Tuero states that "the structured application of the OHSMS reduces hazardous events by establishing standardized protocols and measurable control mechanisms" (Céspedes Tuero 2022). Complementarily, it is argued that integrating safety management with operational objectives supports both incident reduction and the improvement of the organization's overall performance (Ji et al. 2022).

Taken together, the reviewed studies agree that the implementation of good OSH practices must follow an orderly process beginning with diagnosis, planning of controls, continuous training, and verification—elements that support the design of the intervention applied in this study.

3. Methods

The selected methodology is the development of a solution model based on the application of good OSH practices and the implementation of the Lean 5S tool to reduce workplace accidents, following the continuous improvement cycle,

given that this is an improvement project. Lean is a methodology focused on waste reduction to decrease human effort and deliver value to the customer (Huang et al. 2022). The scope of this model includes conducting the research in the production area of a Peruvian metalworking SME during 2023 and validating its effect through the quantification of expected results, aimed at ensuring substantial improvement compared to the initial scenario.

The first stage of the model, Plan, focuses on diagnosing the initial situation based on key inputs such as accident records and statistical data, in order to establish a baseline and measure the level of risk. The next stage, Do, consists of applying the proposed solution tools according to the work schedule and the flowcharts shown in Figures 2 and 3, respectively. After this, in the Check stage, the effects of the implementation are monitored through indicators and audits. Finally, in the Act stage, decisions are made to prevent deviations from the objectives, generating continuous feedback within the model and thus promoting its continuous improvement.

Figure 1 presents the design of the solution model, including the data, engineering tools, activities to be performed, and expected results in each stage. Likewise, Table 1 lists the tools to be used and their respective indicators for the diagnostic phase.

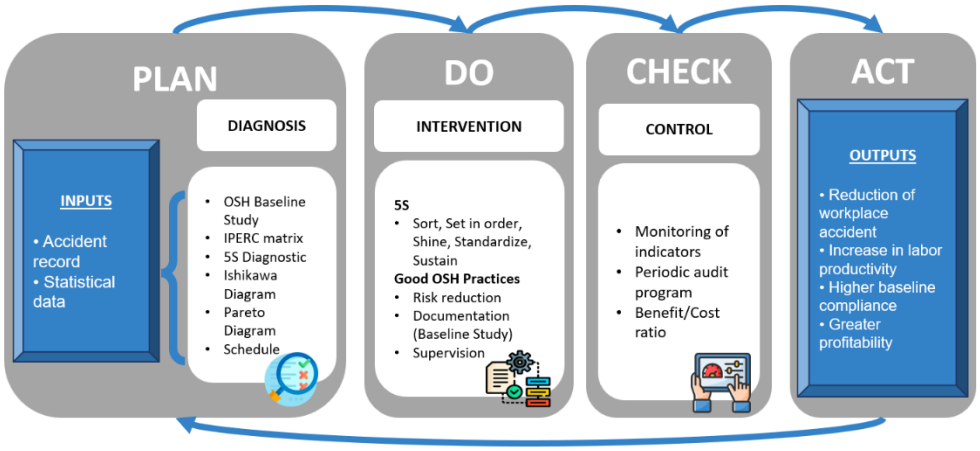

Figure 1. Solution Model Design

Table 1. Diagnostic Indicators

Tool	Indicator
OSH Baseline	OSH Baseline Compliance (%)
IPERC Matrix	Risk level (#)
5S Checklist	5S Checklist Compliance (%)

The following section presents the flow charts for the implementation of the solution techniques.

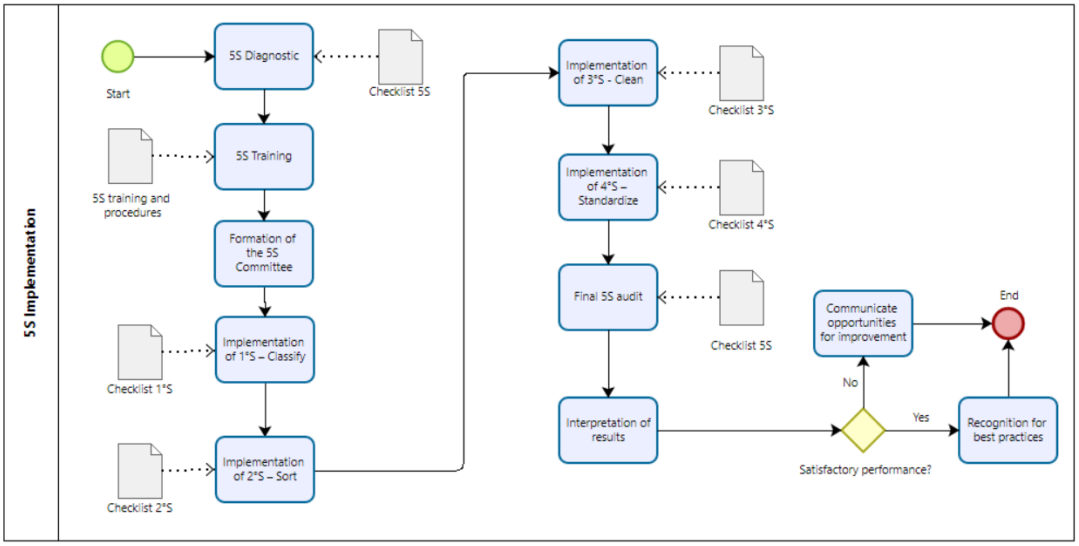

Figure 2. 5S Implementation

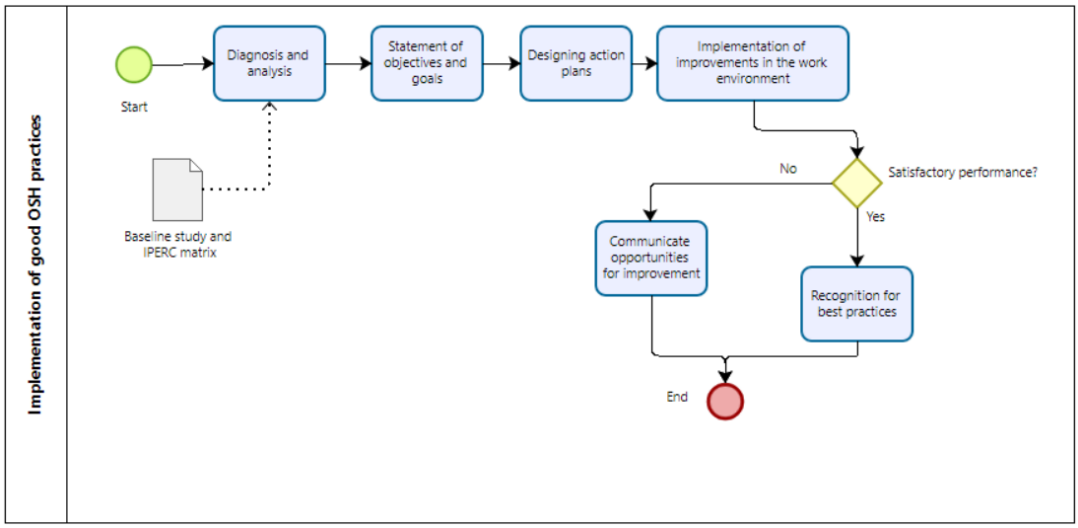

Figure 3. Implementation of good OSH practices

4. Data Collection

The company under study is not exempt from this reality. In 2022, a total of 20 workplace accidents generated costs of $30,395.08, as shown in Figure 4. An accident rate index of 915 was also recorded, highlighting the significant impact of this issue. The accident rate index is a fundamental tool for safety management, as it allows quantification of operational risk levels, evaluation of the effectiveness of preventive measures, and comparison across different areas or periods of analysis. Its interpretation facilitates the identification of patterns in workplace accident occurrence and the development of continuous improvement strategies aimed at reducing workplace accidents and strengthening the organization's preventive culture (Otoole 2002). Continuous monitoring of the accident rate index enables the detection of accident trends, identification of recurring causes, and evaluation of the effectiveness of training and prevention programs implemented, thereby strengthening the company's safety culture (Céspedes Tuero 2022).

MONTH	# ACCIDENTS	HOURS WORKED	FREQUENCY INDEX	# LOST DAYS	SEVERITY INDEX	ACCIDENT RATE INDEX	ACCIDENT RATE (S./H)	EXCHANGE RATE ($/S.)	ACCIDENT COST
JANUARY	1	4,660.00	214.59	9.00	1,931.33	414.45	21.60	3.80	$398.77
FEBRUARY	1	5,152.00	194.10	23.00	4,464.29	866.52	21.60	3.80	$1,019.08
MARCH	3	6,323.00	474.46	19.00	3,004.90	1,425.70	21.60	3.80	$2,525.54
APRIL	3	6,844.00	438.34	16.00	2,337.81	1,024.76	21.60	3.80	$2,126.77
MAY	3	6,139.00	488.68	106.00	17,266.66	8,437.85	21.60	3.80	$14,089.85
JUNE	4	6,454.00	619.77	23.00	3,563.68	2,208.67	21.60	3.80	$4,076.31
JULY	0	8,931.00	0.00	0.00	0.00	0.00	21.60	3.80	$0.00
AUGUST	2	6,998.00	285.80	17.00	2,429.27	694.27	21.60	3.80	$1,506.46
SEPTEMBER	1	7,426.00	134.66	1.00	134.66	18.13	21.60	3.80	$44.31
OCTOBER	2	7,910.00	252.84	52.00	6,573.96	1,662.19	21.60	3.80	$4,608.00
NOVEMBER	0	5,268.00	0.00	0.00	0.00	0.00	21.60	3.80	$0.00
DECEMBER	0	4,165.40	0.00	0.00	0.00	0.00	21.60	3.80	$0.00
ANNUAL AVERAGE	**20**	**76,270.40**	**262.22**	**266.00**	**3,487.59**	**915.00**	**-**	**-**	**$30,395.08**

Figure 4. OSH Statistical Data 2022

Given this situation, the causes behind the workplace accident problem were analyzed, resulting in the identification of two key factors shown in Figure 5: non-compliance with safety regulations (Law 29783) and the lack of order and cleanliness at the workstation.

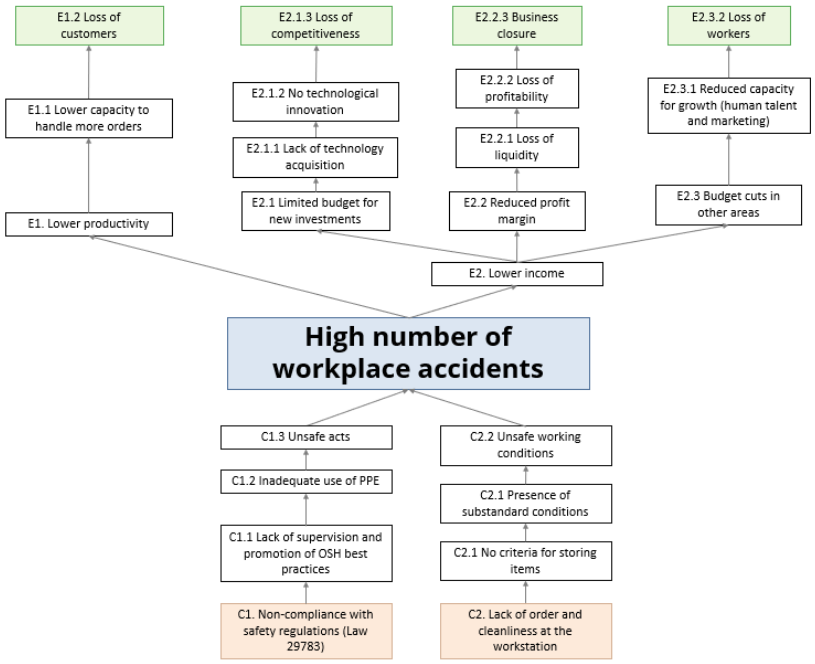

Figure 5. Problem, Impact, and Cause Tree

After applying the initial OSH baseline assessment shown in Table 2, it was found that only 39% of the required activities were in compliance with the standards established by Law 29783.

Table 2. OSH Baseline Diagnostic Results

Guidelines	Activities Completed	% Completed	Activities Not Completed	% Not Completed	Total Activities
Commitment and Involvement	4	40%	6	60%	10
Occupational Health and Safety Policy	7	58%	5	42%	12
Planning and Application	4	24%	13	76%	17

Implementation and Operation	8	32%	16	64%	25
Regulatory Evaluation	6	60%	3	30%	10
Verification	8	33%	16	67%	24
Information and Document Control	10	56%	8	44%	18
Management Review	0	0%	6	100%	6
Baseline Result	**47**	**39%**	**75**	**61%**	**122**

On the other hand, regarding the lack of order and cleanliness at the workstation, a 5S Checklist revealed that the levels of these conditions were very low. The results of the 5S diagnosis are presented in Figure 7, along with images of the workstation shown in Figure 6.

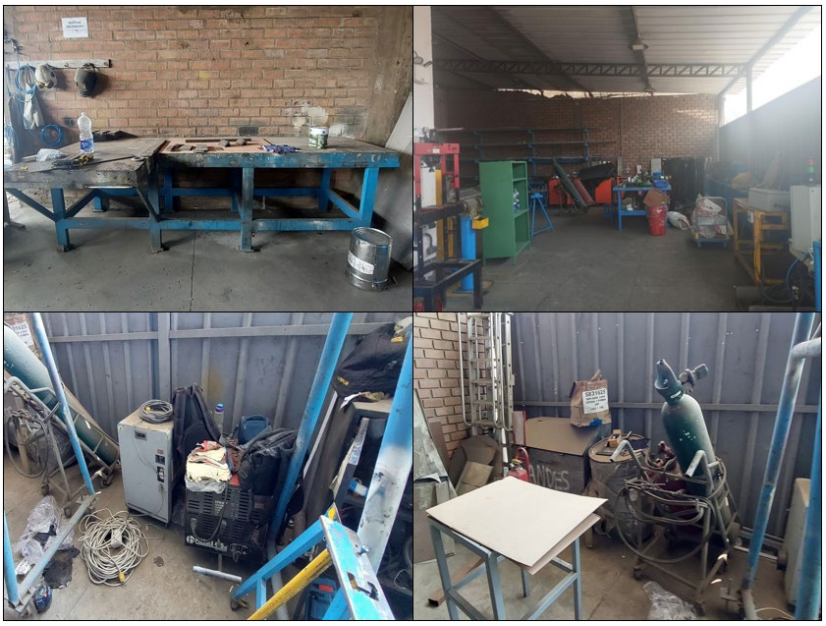

Figure 6. Workstation

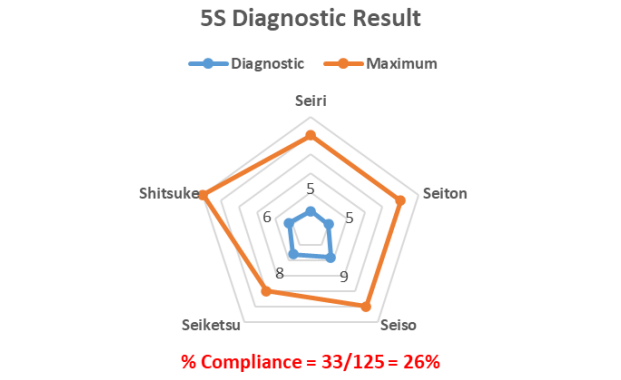

Figure 7. 5S Diagnostic Results

In this way, after identifying and supporting the root causes of the problem under study, the main objectives of this research were established, considering the KPIs to be measured, as shown in Table 3.

Table 3. KPIs for Each Primary and Secondary Objective

Objectives	KPIs	Current	Expected
Reduce workplace accidents	Monthly workplace accidents (#accidents/month)	2	0
Increase compliance with safety regulations	OSH baseline compliance (%)	39%	70%
Reduce the level of exposure to occupational risks	Risk level (#)	14.38	8
Reduce tool and equipment search time	Tool search time (min/operator)	5.4	1.24
Maintain a clean and organized work area	5S Checklist compliance (%)	26%	90%

To achieve these objectives, the solution tools to be used are good OSH practices and the 5S methodology. These tools were selected after an exhaustive review of previous studies that provided the most effective solutions for addressing the problem under investigation.

5. Results and Discussion

5.1 Numerical Results

A detailed identification of the costs associated with the implementation and the total valuation of these costs was carried out. This valuation serves as an input for the development of the economic cash flow, which was selected because no external financing (bank loan) is required for the implementation. Furthermore, an economic cash flow projection was conducted for a period of nine months (11/2023–07/2024), and all calculations were expressed in U.S. dollars (using an exchange rate of 3.8 PEN/USD) (Table 4).

Table 4. Cost Valuation for Improvement Implementation

Implementation Description	Cost (PEN)	Cost (USD)
Area cleaning	14,400.00	4,939.39
Safety signage	359.80	94.68
Wall hooks	169.50	44.61
Training on 5S principles	8,820.00	2,321.05
Training in good OSH practices	6,840.00	1,800.00
External auditor	6,500.00	1,710.53
Training materials	196.90	51.82
Total	**37,286.20**	**10,962.07**

The detailed budget allocated resources effectively to each stage of implementation, as shown in Figure 8, ensuring an efficient and controlled execution. The schedule outlines the project stages and their timelines, providing a clear guide for the successful implementation of the proposed solution.

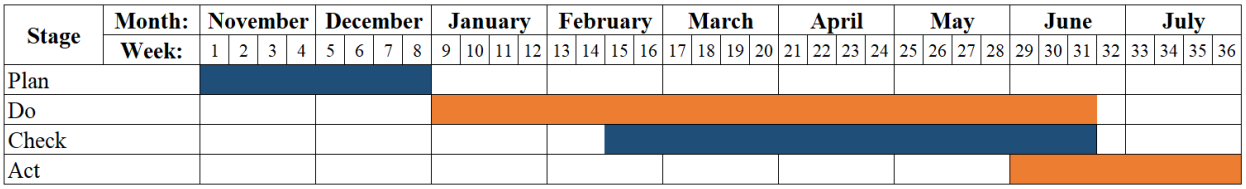

Figure 8. Pilot Schedule

The following section presents the profitability indicators that help assess the feasibility of the project, as they allow measuring profitability based on the projected economic cash flow (Table 5).

Table 5. Profitability Indicators (Economic)

Profitability Indicator	Result
COK	15.94%
Economic NPV	$13,917.10
Economic IRR	47.41%
B/C Ratio	2.27
Payback Period	2.7967 months

- The Internal Rate of Return (IRR) stands out with a solid 47.41%, a value higher than the opportunity cost (COK), indicating feasibility.
- The Net Present Value (NPV) is calculated by discounting future inflows and outflows, subtracting the initial investment. The NPV reaches $13,917.10.
- The Benefit-Cost Ratio (B/C) exceeds 1, with a value of 2.27, indicating that the updated economic benefits of the project exceed its costs.
- The investment is recovered within a period of 2.7967 months

5.2 Graphical Results

The pilot test in the welding area showed significant improvements after the joint implementation of 5S and good OSH practices. The structured application of 5S—through the initial audit (Table 6), training, establishment of a committee, and constant correction of deviations during implementation—allowed the elimination of substandard conditions, reduction of risks, and optimization of organization through visual controls (Pérez & Quintero 2017). The lack of standards had generated disorder and loss of materials and equipment in the workshop (Figure 9). Similarly, waste and scrap present at the workstation increased the risk of accidents, a situation also evidenced in studies where the 5S methodology reduces waste and improves operational efficiency (Rodrigues et al. 2020). The final audit confirmed substantial progress in orderliness and operational efficiency (Prashar 2018).

In parallel, the strengthening of the OSH Management System, in accordance with Law 29783, ISO 45001:2018, and the preventive and corrective measures applied after the baseline diagnosis and implementation of the IPERC matrix, led to a significant reduction in incidents and accidents. This aligns with studies demonstrating the effectiveness of such systems in industrial environments (Céspedes Tuero 2022) and with ILO recommendations regarding occupational risk prevention and the reduction of costs associated with accident rates (International Labour Organization 2021). Continuous monitoring helped consolidate safer workstations and contributed to the sustainable and competitive performance of operations (Anaya 2017).

Figure 9. Initial Situation vs. Final Situation

Table 6. Results of the Improvement Proposal

Tool	KPI	As Is	Target	To Be	Variation
Good OSH Practices	Monthly workplace accidents (#accidents/month)	2	0	0	100%
	OSH Baseline Compliance (%)	39%	70%	75%	92%
	Risk level (#)	14.38	8	3.38	76.50%
5S	Tool search time (min/operator)	5.4	1.24	1	81.48%
	5S Checklist Compliance (%)	26%	90%	94%	262%

a) KPI 1: Monthly workplace accidents (#accidents/month)
Previously, an average of two workplace accidents per month were recorded, a figure that was reduced to zero following the implementation of strict safety practices and the promotion of order and cleanliness at the workstation. This achievement demonstrates the direct impact of the proposed model on reducing workplace accidents, reinforcing its effectiveness.

b) KPI 2: OSH baseline compliance (%)
Regarding compliance with Occupational Safety and Health (OSH) regulations, a significant increase was observed—from 39% to 75%. This improvement is associated with continuous personnel training, the strengthening of the preventive culture, and adherence to the OHSMS. Alignment with OSH requirements ensures safer working conditions and conformance with established standards, reinforcing the company's commitment and responsibility toward occupational safety.

c) KPI 3: Risk level (#)
Occupational risk management showed remarkable progress, with the risk level decreasing from 14.38 (moderate) to 3.38 (tolerable). The elimination of substandard conditions—such as the implementation of visual controls—along with periodic evaluations and the promotion of a safety-oriented culture were essential to this improvement, demonstrating the effectiveness of the selected tools.

d) KPI 4: Tool search time (min/operator)
In terms of operational efficiency, tool search time was drastically reduced from 5.4 minutes to 1 minute per operator. The implementation of 5S ensured an efficient organization of the workstation, optimizing the availability and accessibility of tools.

e) KPI 5: 5S Checklist compliance (%)
Compliance with the 5S Checklist also showed a significant improvement, increasing from 26% to 94%. Emphasis on maintaining standards, assigning responsibilities, and providing adequate resources helped ensure that the workspace remained clean and orderly, resulting in a positive impact on efficiency and worker well-being.

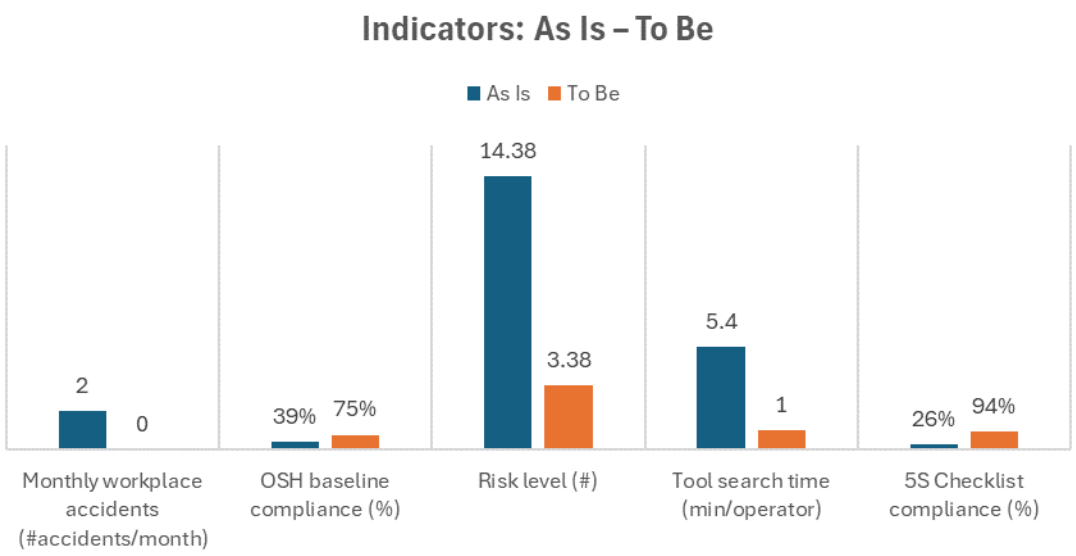

Figure 10. Indicators: As Is – To Be

Figure 10 shows the indicators presented in the original scenario (As Is) contrasted with the new scenario after the improvement was implemented (To Be). The reduction in accidents, the increase in regulatory compliance, and the improvements in operational efficiency are noteworthy.

5.3 Proposed Improvements

This pilot will be applied to the welding area within the production department, as it is the area with the highest number of recorded workplace accidents during the 2022 analysis period, as shown in Figure 11.

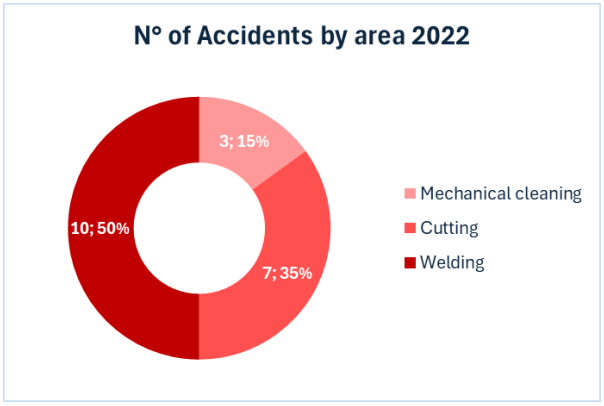

Figure 11. Accidents by Area 2022

The pilot aims to contribute to the Occupational Health and Safety Management System (OHSMS) of the organization under study, which is supported by its Occupational Health and Safety Committee (OHSC), by adding value through the development of procedures and controls based on good OSH practices. To achieve this, the objective is to reduce the level of risk to which welders are exposed by improving working conditions. This outcome will be reflected in the IPERC matrix, which will show the reduction in risk when comparing the initial and final scenarios. If successful, the pilot can be scaled for implementation across the entire production area.

Risk reduction will decrease accidents through good OSH practices such as the elimination of substandard conditions, the implementation of visual controls, the use of personal protective equipment (PPE), and the installation of shelving

to organize tools and materials. Table 7 details the phases of the pilot, the stages, and the engineering tools to be used in each stage.

Table 7. Pilot Phases and Engineering Tools

Phases	Stages	Tools
1. Assessment of the Current Situation	Plan	Process Sheet, Ishikawa Diagram, IPERC matrix, OSH Baseline, 5S Checklist
2. Goal Definition	Plan	KPIs
3. Training and Education	Plan	Manuals, 5S Forms, Training Records
4. Communication and Awareness	Plan	Posters, Talks
5. Implementation of Improvements	Do	Gantt Chart, Visual Controls, Risk Map, Shelving
6. Documentation and Reporting	Check	Manuals, 5S Forms
7. Final Evaluation	Act	KPIs, IPERC, OSH Baseline, 5S Checklist

5.4 Validation

- **Interpretation of results:** By comparing the initial results (As Is) with the final results (To Be) and identifying the variation between them in Table 5, it is possible to answer the proposed research question: "How does the application of a risk prevention model impact the reduction of occupational accidents in a Peruvian metalworking micro-enterprise?"

  This research demonstrated a positive impact, as favorable variations were obtained in all the declared indicators. The selected solution tools and engineering tools used both in the diagnostic phase and in the implementation of the pilot were key to surpassing the proposed goals, thus achieving the main objective of this study: reducing the number of workplace accidents in the production area of a Peruvian metalworking micro-enterprise through good OSH practices and 5S.

- **Comparison of results and identified limitations:** The research presents results similar to previous studies, highlighting improvements in the reduction of substandard conditions and exposure to occupational risks, both of which positively impact productivity by optimizing operational times and reducing workplace accidents.

  The main limitation was the lack of technological innovation in operations, as automation could reduce exposure to high-risk tasks such as welding. This limitation was due to budget constraints, since the investment required for automation exceeded the budget allocated for the pilot.

6. Conclusion

The application of the occupational risk prevention model in the production area of a Peruvian metalworking micro-enterprise proved to be both effective and viable, as the pilot met and exceeded the established goals and demonstrated economic profitability.

Good OSH practices enabled a 100% reduction in workplace accidents and a 76.50% decrease in the risk level through the elimination of substandard conditions and the implementation of visual controls.

The implementation of 5S contributed directly to operational improvement, evidenced by an 81.48% reduction in tool search time and a 94% compliance level in the 5S Checklist, surpassing the initial objective and enhancing productivity.

From an economic perspective, the model proved to be profitable, yielding an Economic NPV of $13,917.10, an Economic IRR of 47.41%—higher than the 15.94% COK—and a benefit/cost ratio of 2.27, indicating that for every dollar invested, $1.27 of net benefit is gained. Furthermore, the payback period of 2.79 months confirms financial viability and rapid liquidity generation.

Overall, the pilot results demonstrate the effectiveness and scalability of the model for full implementation in the production area.

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