IMPROVING PRODUCTIVITY IN AN SME IN THE METALWORKING SECTOR THROUGH LEAN MANUFACTURING AND TPM TOOLS: A CASE STUDY IN PERU

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ABSTRACT

The objective of this study is to increase the efficiency and productivity of a business that offers sandblasting and painting services. An integrated model incorporating lean manufacturing tools, including preventative and autonomous maintenance, 5S, and SMED, is presented in this article. The model consists of four distinct phases. The initial stage consists of diagnosing the company's beginning state. The second stage entails the execution of the 5S methodology to arrange workstations. Following this, a maintenance programme was implemented, which ultimately resulted in the reduction of setup times for the painting machine configuration. Furthermore, an assessment was conducted on the realised enhancements, and metrics were compared both before and after deployment. Statistical validation was performed via a pilot study that occupied an extended period. The findings validated a productivity improvement of 10% and an efficiency increase of 23.8%. In addition, a 32.04% reduction in setup time was observed.

OPSOMMING

Die doel van hierdie studie is om die doeltreffendheid en produktiwiteit van 'n besigheid wat sandblaas- en verfdienste bied, te verhoog. 'n Geïntegreerde model wat skraal vervaardigingsgereedskap insluit, insluitend voorkomende en outonome instandhouding, 5S en SMED, word bespreek. Die model bestaan uit vier verskillende fases. Die aanvanklike stadium bestaan uit die diagnose van die maatskappy se begintoestand. Die tweede fase behels die uitvoering van die 5S-metodologie om werkstasies te bestuur. Hierna is 'n instandhoudingsprogram geïmplementeer, wat uiteindelik gelei het tot die vermindering van opsteltye vir die verfmasjienkonfigurasie. Verder is 'n assessering gedoen oor die gerealiseerde verbeterings, en numeriese uitsette is beide voor en na ontplooiing vergelyk. Statistiese validering is uitgevoer via 'n loodsstudie wat 'n lang tydperk in beslag geneem het. Die bevindinge het 'n produktiwiteitsverbetering van 10 persent en 'n doeltreffendheidverhoging van 23.8 persent bevestig. Daarbenewens is 'n vermindering van 32.04 persent in opstel tyd waargeneem.

1. INTRODUCTION

The metalworking sector has shown a growth trajectory since 2022, and it is expected to reach $12.85 billion by 2027, with a Compound Annual Growth Rate (CAGR) of 3.9%. However, the war between Russia and Ukraine has complicated the post-pandemic economic recovery, leading to sanctions, inflation, and disruptions in supply chains. [1] In Latin America, a positive outlook is anticipated, with projected increases in annual industrial production by 2024 in countries such as Uruguay (3.7%), Colombia (2.8%), Brazil (2.7%), Mexico (2.5%), and Peru (2.1%) [2].

The importance of the metalworking industry in Peru was highlighted by considering its impact on economic development. In 2021, it represented 11.2% of the gross value added of the Peruvian manufacturing industry, equivalent to 71.636 billion PEN soles, and contributed 1.5% to the country's gross domestic product, reaching 551.714 billion PEN soles. These figures underscored its economic relevance and influence in the Peruvian context. The business structure comprised approximately 64,949 formal entities, where micro- and small enterprises (MSEs) represented 99.5% of the total. This dynamic was explained by the limited development of the metalworking industry, which did not favour the growth of microenterprises, while large companies maintained a dominant position [3].

Although the production of the Peruvian metalworking industry experienced an average annual decrease of 4.2% between 2017 and 2020, with more pronounced declines in 2017 (-4.3%) and 2020 (-26.8%), 2021 showed an unusual growth of 49.3%, influenced by statistical factors and gradual recovery along with pandemic vaccination [4]. Despite expectations of operating at 50% capacity, the industry operated below that limit, reaching a maximum of 40%, according to a report by the Peruvian Association of Metalworking Companies [5].

Therefore, it was crucial for most companies in this industry to evaluate their productivity and efficiency in all operational processes, as this directly affected the quality of the product and the provision of high-level services to customers. From a review of the literature, it was observed that several studies mentioned the implementation of lean manufacturing techniques in companies in the metalworking sector. Therefore, it was imperative to validate the effectiveness of the application of these tools to optimise productivity in small and medium enterprises (SMEs) in this industrial sector.

Lean manufacturing had been successful in various industries and had improved competitiveness and operational efficiency. In addition to continuous improvement, it was essential to reduce waste and optimise resources. Its application also promoted an innovative and adaptable organizational culture, reinforcing the companies' ability to face changing challenges in the business environment [6].

The implementation of lean manufacturing principles in a project improved efficiency by eliminating waste and focusing on value creation in various sectors. However, despite the positive results demonstrated by lean manufacturing methodologies, their application in the metalworking industry, specifically in industrial painting and sandblasting, had been scarcely explored. Therefore, this study proposed an innovative application of such tools to improve the productivity of the sandblasting and industrial painting process of metalworking structures in an SME in the metalworking sector. The objective was to identify and eliminate bottlenecks and to optimise current methods using tools such as 5S, Total Productive Maintenance (TPM), and Single-Minute Exchange of Die (SMED).

The novelty of this study lay in several aspects:

- Specific context of SMEs in Peru: Unlike most studies that focused on large companies, this work centred on a Peruvian SME, providing solutions tailored to its characteristics and limitations.
- Integration of lean manufacturing and TPM: The combination of these methodologies in an SME environment was an innovative approach that demonstrated how they could be integrated to improve productivity and efficiency.
- Practical adaptations and empirical results: The study offered empirical results that were validated through a pilot study, including quantifiable improvements in productivity, efficiency, and setup times.
- Focus on sustainability and continuous improvement: The implementation of 5S, autonomous and preventive maintenance, and SMED underscored the importance of sustainability and continuous improvement in operational management.

This research not only validated the techniques mentioned in previous studies, but also provided new perspectives and specific adaptations for the sector and the Peruvian context, thus contributing to the academic and practical literature in industrial engineering.

2. PROBLEM

The case study research was conducted in a small and medium-sized enterprise (SME) in the metal-mechanic sector located in Lima, Peru. The company provides sandblasting, shot blasting, and industrial epoxy painting services with a high-pressure system designed for metal structures. Additionally, it has extensive work areas and offers personalised services to various sectors such as the mining industry, shipping companies, manufacturers of metal structures, and concrete plants. However, the 2022 annual report revealed a significant increase in unproductive times during painting and sandblasting operations, specifically in the production line of square tubes. These increases not only caused significant losses, but also created disorder in the production area, leading to unmet customer expectations.

The issue discovered in this industry, as determined by a review of the relevant literature, is attributable to a few causes, including an excessive number of nonconformities, machine malfunctions or jams, inadequate planning, and lengthy setup times. As a result, organizations show sub-optimal levels of efficiency in their work procedures. Extended client product delivery periods, rework, and defective items are the primary reasons for this. The lack of application of work tools, such as method improvement, generates dissatisfaction about customers' deliveries [7]. To identify the main problem reducing productivity in the company, a Pareto analysis was conducted, as illustrated in Figure 1.

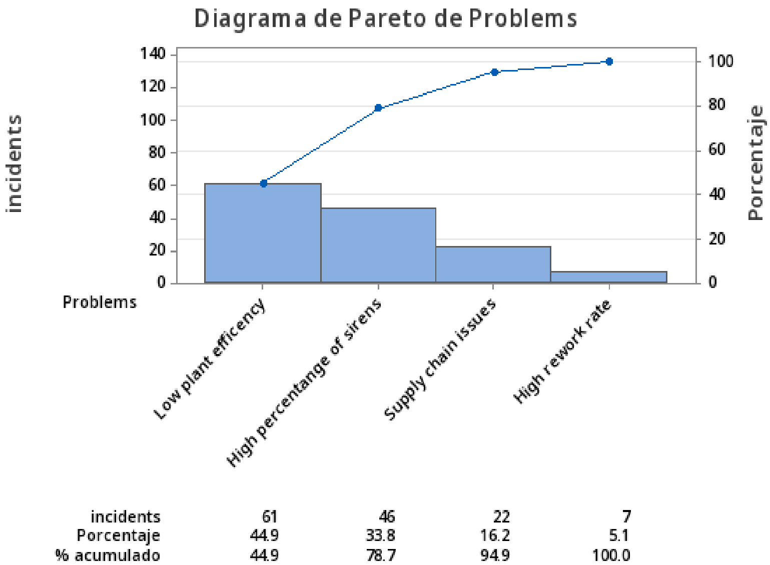


Figure 1: Pareto diagram: Causes of excessive amount of wastage

When performing the Pareto analysis, it was observed that one of the predominant causes of waste could be attributed to the low efficiency of the plant, representing an accumulated 45% of the main reasons for excess waste. To get insight into the operational efficiency of the organisation under consideration in this case study, data pertaining to the overall equipment effectiveness (OEE) metric for the preceding fiscal year was obtained. This indicator is often acknowledged as the most efficacious and streamlined instrument for fostering enhanced productivity in the manufacturing setting.

As shown in Table 1, the small and medium-sized enterprise (SME) that was examined demonstrated an unsatisfactory level of overall equipment effectiveness (OEE) with an average score of less than 65%, which is regarded as the threshold for worldwide standards. This resulted in substantial economic repercussions and a decrease in competitive position. It is important to note that, with the increase in production costs, there is a corresponding decrease in profit margins. The aforementioned research suggests that, in comparison with other factors, the specified indicator was primarily impacted by a low availability rate.

Table 1: Monthly historical data of the OEE indicator

Month	Availability	Performance	Quality	% OEE
January	79.65%	91.83%	87.54%	64.033%
February	81.50%	90.88%	87.72%	64.974%
March	83.41%	83.80%	87.03%	60.831%
April	81.12%	89.04%	87.37%	63.107%
May	81.52%	91.08%	87.69%	65.113%
June	81.45%	90.93%	87.76%	65.001%
July	80.50%	89.25%	87.32%	62.737%
August	80.64%	89.58%	87.47%	63.186%
September	80.45%	89.18%	87.18%	62.551%
October	80.29%	93.07%	87.79%	65.600%
November	79.65%	91.83%	87.44%	63.153%
December	81.50%	90.88%	87.56%	63.578%

This could be visualised through the creation of a root cause analysis tree, in which the causes of the problem are outlined. In this case, low productivity and the identification of its main causes were highlighted, allowing the implementation of effective solutions and the prevention of recurring problems.

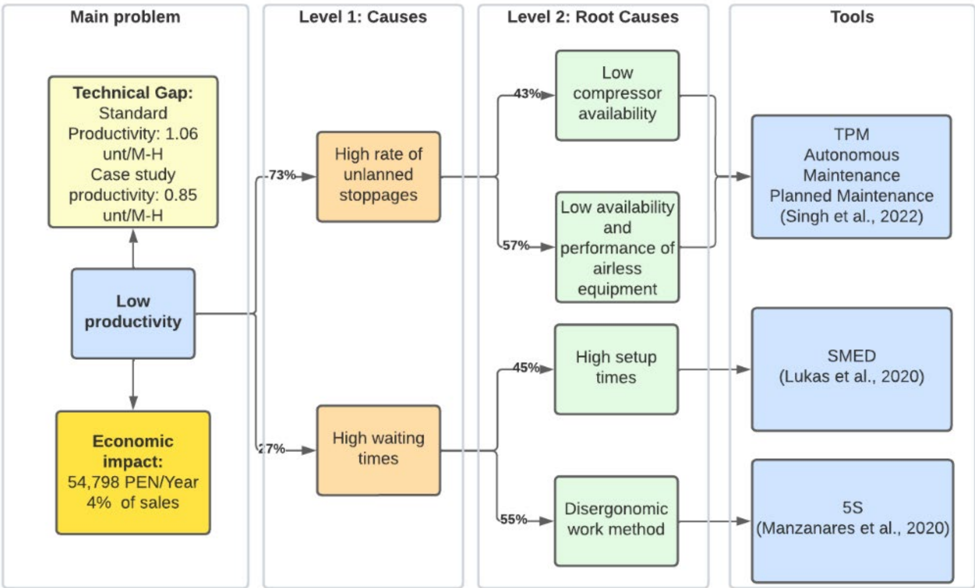


Figure 2: Linking tools to the causes of the problem

3. BACKGROUND

Companies currently face a highly dynamic environment that demands increased competitiveness. This involves enhancing the quality of their processes and services to adapt to change, survive, and thrive in the market [8]. Therefore, companies adopt a lean manufacturing methodology as a consolidated alternative.

Lean manufacturing:

This is a set of techniques designed to increase value creation by reducing all kinds of waste [9]. Its main pillars relate to material flow, quality assurance, machinery, and human factors. In addition, lean manufacturing adapts effectively to mass production environments with low process variability and high and consistent demand [10].

A literature review confirms that companies seek sustainable improvement in their products, services, or processes through continuous improvement, employing lean manufacturing practices [11]. In the current context, these practices have proven successful by providing an organised and efficient approach to increase productivity through eliminating or reducing time-consuming actions that do not add value [12]. The results derived from the application of lean manufacturing using its tools are presented. The associated philosophy is structured into phases to be followed, ensuring proper implementation that leads to success in business processes [13].

This is exemplified in a recent study showing how to improve productivity in a small manufacturing company using lean manufacturing tools. Significant improvements are highlighted, challenging common perceptions and demonstrating the effectiveness of these practices in smaller-scale enterprises. Techniques such as value stream mapping, Kaizen, 5S, standard work, and others were applied, resulting in notable reductions in production times and quality defects. The lean methodology led to a 65% improvement in waiting times and a 29% improvement in annual working times, focusing on the identification and elimination of valueless activities [11].

On the other hand, several authors emphasise the need to employ multiple lean tools to achieve a positive impact on productivity. A study focused on improving the machining process in a manufacturing industry through the action research methodology. The author used process flow mapping and product selection to identify and analyse key issues in the sector. Proposing solutions, various lean tools were applied, such as SMED to improve productivity times, JIT based on planning rather than on continuous and unlimited supply, and the implementation of a double-check procedure to mitigate operator errors, among others. The results revealed significant improvements, with a 59% reduction in handling time for parts up to 1 000 kg. In addition, there was a decrease of 2.04% in external non-conformities and a decrease of 3.99% in internal non-conformities, indicating advancements in process quality and efficiency [14].

In another study it was argued that the partial implementation of TPM, focusing on certain pillars, yielded positive results, especially in reducing corrective interventions and machinery breakdowns. The application of the 5S methodology contributed significantly to a 38% decrease in corrective maintenance actions in CNC milling centres. Likewise, breakdown reduction goals were achieved through the execution of asset management and preventive maintenance plans, achieving reductions of 23% and 38% in CNC lathe and CNC milling centre breakdowns respectively. The successful implementation of these measures was reflected in the improvement of key indicators such as OEE, MTTR, and MTBF [15].

5S

The implementation of the 5S methodology has proven to generate positive results in various settings, including industrial, retail, and educational environments [16]. In the industrial minerals sector, a 58.8% reduction in material waste was achieved. In the manufacturing realm, a company experienced improvements in productivity, with a significant increase in the average audit score, rising from 2.8 to 4.03, and a consequent increase of 1.21 kg/h-h in production efficiency [17]. Moreover, audits in other studies showed increases ranging from 14.8% to 82.8%, highlighting the versatility and effectiveness of the 5S methodology, with the benefit of bringing about economic savings [18].

TPM

Total productive maintenance (TPM) is a strategy aimed at enhancing the effectiveness of industrial enterprises and improving the performance of their equipment during operations [19]. It focuses specifically on addressing waste issues in production systems [20]. The fundamental goals of TPM include reducing failures, minimising repair times, eliminating micro-stoppages, and reducing losses overall. In this context, metrics such as MTTR (Mean Time To Repair), MTBF (Mean Time Between Failures) and OEE (Overall Equipment Effectiveness) used are employed to assess the performance of the production system [21].

TPM is based on seven pillars, with autonomous and preventive maintenance being highlighted. The former involves activities aimed at training workers to detect anomalies and perform simple repairs. The latter involves inspections and adjustments to prevent failures and extend the equipment's lifespan [22]. The implementation of TPM has gained popularity owing to its impact on organizational responsiveness and meeting customer demands [23]. In a metal-mechanic industry, it resulted in an efficiency increase from 2% to 6% [19]. In another scenario, facing low availability issues in an injection plant, the application of TPM raised the overall equipment efficiency from 57% to 68% [22]. Overall, TPM can enhance efficiency in various industrial settings.

SMED

SMED, or 'single minute exchange of die', is a tool for reducing changeover times in production [24]. It has proven to be effective in sectors such as automotive, textile, and metal-mechanic, generating notable cost and time savings. Leading countries in its implementation, such as Portugal, China, India, and the United States, support its global applicability. Reductions in machinery setup times and improvements in production capacity have been revealed [25]. The integration of SMED with other methodologies emphasises the need to adapt approaches to address specific problems and maintain global competitiveness [26]. In conclusion, SMED emerges as a crucial strategy for reducing changeover times and improving operational efficiency [27]. The study in the metal-mechanic sector demonstrates the contribution of SMED with an emphasis on increasing industry productivity.

Integration and adaptation of lean and TPM tools in SMEs in the metalworking sector

To contextualise the article within the existing theoretical and practical framework, it is essential to establish a robust connection with the key literature in the field of industrial engineering. The seminal studies of [28], [29] and [30] provide a solid basis on which to compare and contrast our work.

In his work A revolution in manufacturing [28], Shingo introduced fundamental concepts about continuous improvement and waste elimination – principles that underlie the philosophy of lean manufacturing. Shingo highlighted the importance of a mindset oriented to constant improvement and operational efficiency – elements that are central to our study. However, our specific focus on combining lean tools with TPM in SMEs in the metalworking sector broadens this theoretical base by adapting it to a less explored context.

On the other hand, in The lean toolbox, 6th edition, [29] offer comprehensive guidance on lean tools such as value flow mapping, 5S, OEE, and TPM. These authors emphasise the versatility and applicability of these tools in various industries. Our study is based on this versatility, demonstrating how these tools can be effectively implemented in an SME in the metalworking sector in Peru. In addition, our research addresses the specific limitations and difficulties of this context, providing a practical and applied perspective that complements the theory presented by [29].

In TPM: A foundation of operational excellence, [30] present a complete 11-stage TPM model, highlighting the importance of active staff participation and autonomous and preventive maintenance. Our study integrates these concepts by implementing two of the fundamental pillars of TPM, adapting them to the needs and capabilities of an SME. This approach not only validates TPM's relevance in improving operational efficiency, but also demonstrates how its application can be adjusted to maximise results in resource-constrained environments.

4. INNOVATIVE PROPOSAL

From the literature review and existing knowledge, an innovative model was developed, detailed in Figure 3, including inputs, outcomes, KPIs, and the sequence of phases. The information for this model was based on the analysis of the current situation, workplace organization, execution of the maintenance plan, and reduction of setup times. As part of the research, a testing plan was carried out over a period of two months in order to ensure the effectiveness of the implementation process.

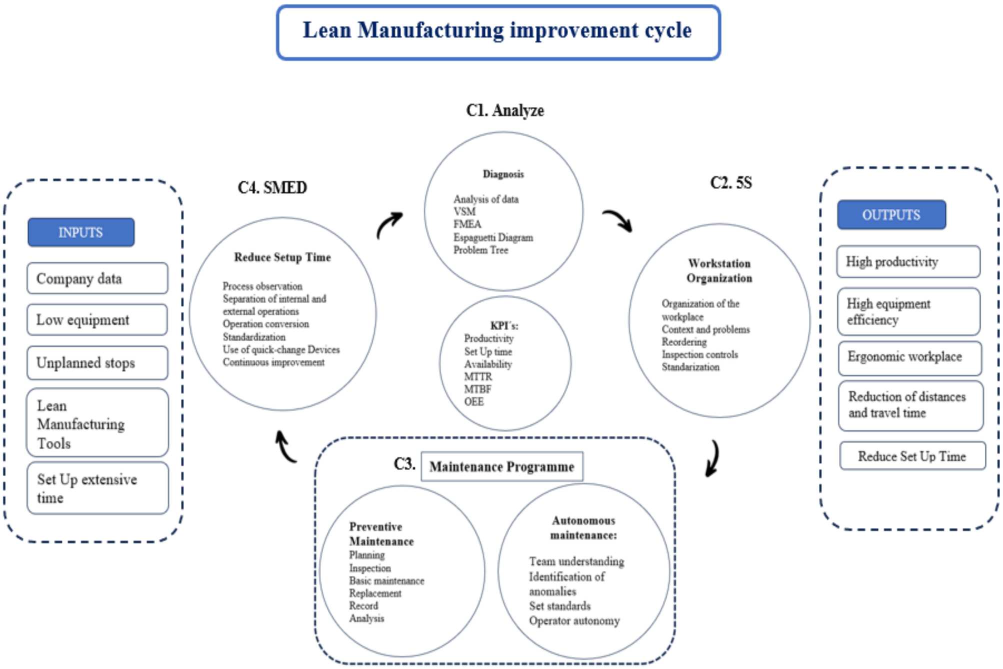


Figure 3: Innovative proposal

The main objective of this research was to demonstrate that the implementation of the proposed model could generate significant improvements in ergonomic conditions, increased availability, and reduced setup times compared with existing models documented in the literature. The overall goal was to boost productivity. The research introduces a problem-solving model that incorporates tools such as 5S, two pillars of TPM (preventive maintenance, autonomous maintenance), and SMED, as illustrated in Figure 3. It is anticipated that these tools will contribute to the achievement of the established objectives.

The integration of lean tools, highlighted in this study, plays a crucial role in improving the daily performance of operators, simplifying tasks, and maintaining well-organised workspaces. At the same time, it establishes a solid foundation for the adoption of continuous improvement practices. This in turn fosters a culture of constant evaluation and progressive optimisation of operational processes.

The methodology applied in this study is divided into four main phases: (1) a diagnosis of the initial state of the company; (2) implementation of the 5S methodology for organising jobs; (3) implementation of a maintenance programme to reduce the set-up times of painting machines; and (4) evaluation of the improvements made through a pilot study. Each phase is detailed in Section 5, illustrating the specific procedures and tools used.\

4.1. Model indicators

During this stage, the indicators mentioned in Table 2 enable a visualization of the reduction of losses in each phase.

Table 2: Level of indicators for the company's objectives

Objective	Indicator/Formula	As is (Initial value)	Objective	Source
Increase the productivity of the company	$Productivity = \frac{m^2 \text{ produced}}{\text{Total man−hours utilised}}$	1.08 m^2/M-H	1.12 m^2/M-H	[17],[22]
Reduce setup time	$Set\ Up\ Time = \sum(Set\ up\ activities\ time)$	52 minutes	28 minutes	[19],[20]
Increase mean time between failures	$MTBF = \frac{\text{Total Operating Time}}{\text{Number of Failures}}$	324.57 minutes	400 minutes	[21],[22]
Reduce mean time to repair	$MTTR = \frac{Total\ Repair\ Time}{Number\ of\ Repairs}$	75.61minutes	20 minutes	[21],[22]
Increase availability	$Availability = \frac{MTBF}{MTBF−MTTR}$	82%	89%	[19],[20],[21]
Increase OEE	$Availability\ x\ Quality\ x\ Performance$	63.37%	95.60%	[19],[22],[23]

5. IMPLEMENTATION

The implementation of lean manufacturing is presented as a strategic necessity to strengthen business efficiency and competitiveness. By eliminating waste and fostering a culture of continuous improvement, this approach redefines how organisations meet challenges, emphasising the importance of adaptability and operational excellence. In the paragraphs below we explore how this transformation enhances the processes in the company studied.

5.1. Stage 1: Case diagnosis

First, data from the studied company were gathered to identify the impact of the causes of the problem, determine root causes, and define the key products that had the greatest impact on sales. The study was conducted using tools such as ABC analysis, a Pareto Diagram, a Spaghetti Diagram, the FMEA matrix, and Value Stream Mapping.

5.2. Stage 2: Application of the 5S tool

Through the implementation of the 5S tool, it was possible to keep workspaces more organised, facilitating the identification of tools, reducing the time spent searching for them, and increasing workers' awareness of the 5S principles. In addition, it improved ergonomic conditions in the painting booth, resulting in enhanced work performance. Figure 4 details the steps taken to carry out this implementation.

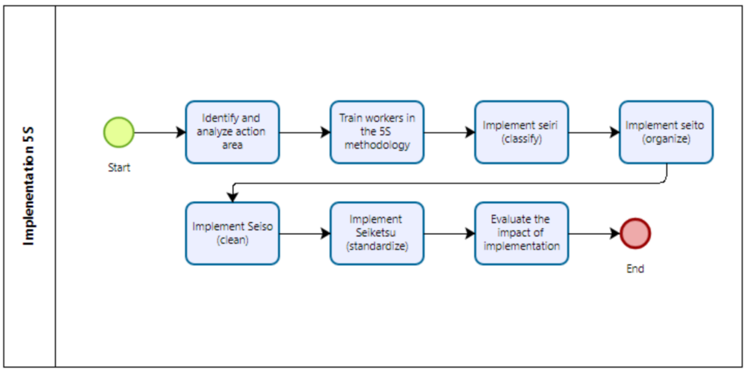


Figure 4: Micro-design 5S

This stage began with a visual inspection of the initial conditions of both booths, as well as the use of forms to assess their initial situation, as shown in Table 3.

Table 3: The initial status of the work areas

Current situation: sandblasting area	Current situation: painting area
	
	

Then the implementation started using checklist forms and red cards. Then the tools and elements found were organised. Afterwards, a general cleaning of the booths was carried out with their respective inspection sheets. Then the area where the work table, tool board, and SMED cart would be installed was marked with yellow tape. Finally, the staff was trained in 5S, policies were established, and a cleaning plan was developed. Table 4 shows each step. Figure 10 displays the final conditions of both booths, with a comparison using the radial diagram before and after.

Table 4: 5S implementation

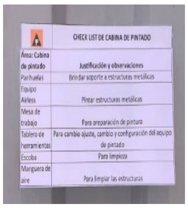
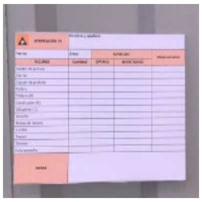
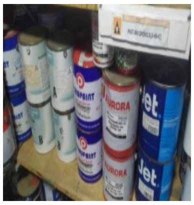
Implementation of 5S in the painting and sandblasting area				
Seiri				

Table 4: 5S implementation (cont.)

Implementation of 5S in the painting and sandblasting area				
Seiton				
				
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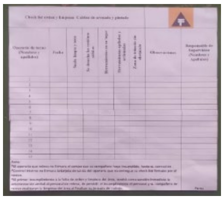
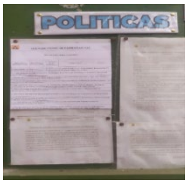
				
Seiketsu				
Shitsuke				
				

5.3. Stage 3: SMED implementation

START OF THE SMED DEPLOYMENT

Making times

The observation of painting activities and their time measurements confirmed that the paint change in the equipment took about 50 minutes. This finding was supported by 10-time measurement samples of the 19 activities involved in the change. It is important to note that, during this process, the painting activity was interrupted, leading to considerable delays and wait times. To address this, the implementation of SMED (single-minute exchange of die), a tool designed to differentiate and minimize setup planning times, was proposed in order to reduce the setup duration from hours to minutes [31]. This approach was carried out following the steps detailed in Figure 5.

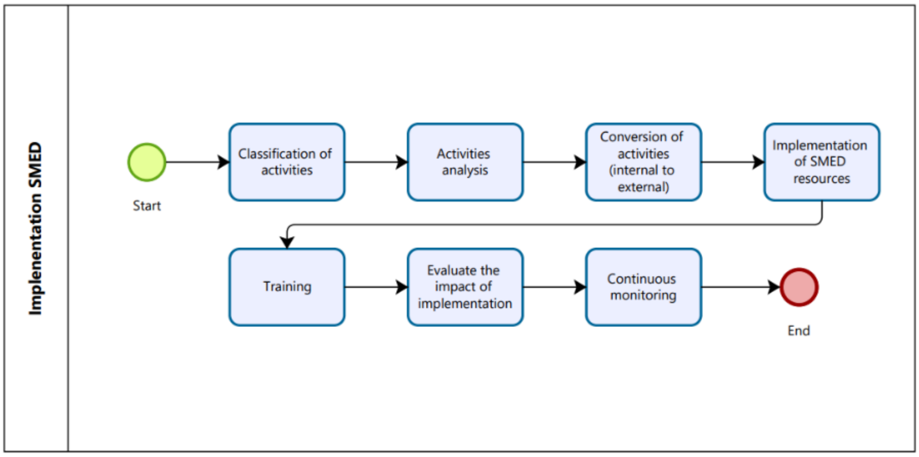


Figure 5: Micro-design SMED

5.3.1. Convert internal operations into external operations

After determining whether the activities were internal or external, we proceeded to examine which of the internal activities (IA) could be transformed into external activities (EA). To achieve this, we applied specific techniques or methods with the purpose of reducing (R), simplifying (S), combining (C), or eliminating (E) the duration of each of these internal activities.

Machine:	Equipo graco Ultramax 695 Stand								**IMPROVEMENT**		
date:	1/09/2023										
Operator:	Christian Huaman Echevarria										
ACTIVITIES	**Activity: Paint change**			**ECRS ANALYSIS (Fill in with X if the activity can be E, C, R o S)**							
	Internal activity	External Activity	Time (min)								
Ei	**Activities**	**E**	**C**	**R**	**S**	**IA**	**EA**	**Time (min)**	**Ei**	**Elements**	**Time (min)**
E1	The operator from the painting booth goes to the tool store to request nozzle, strainer, rags, gloves, 2 empty buckets and adjustment tools.	X				X		5.23	**A1**	Operator takes SMED cart from the painting booth, goes to the tool warehouse to request and collect resources.	3.1
E2	Operator brings tools to the painting booth and arranges them at his discretion.	X				X		5.29	**A2**	Operator goes with SMED cart to the paint warehouse to pick up paint (a+b+c).	1
E3	Operator goes to the tool warehouse to request resources (resin, catalyst, diluent and thinner)	X				X		3.9	**A3**	Operator brings resources with SMED cart to the painting booth and arranges them at his discretion on the work table.	3.7

Machine:	Equipo graco Ultramax 695 Stand
date:	1/09/2023
Operator:	Christian Huaman Echevarria

ACTIVITIES	Activity: Paint change			ECRS ANALYSIS (Fill in with X if the activity can be E, C, R o S)						
	Internal activity	External Activity	Time (min)							
Ei	**Activities**			**E**	**C**	**R**	**S**	**IA**	**EA**	**Time (min)**
E4	Operator goes to the paint warehouse to collect resources (resin, catalyst, thinner and thinner)			X				X		2.93
E5	Operator brings resources to the painting booth and orders them at his discretion.			X				X		5.51
E6	Operator opens gallons and pours components (resin, catalyst and diluent) into a bucket						X	X		0.38
E7	The components are manually mixed in the bucket to obtain the paint						X	X		2.72
E8	In a separate bucket the operator strains the paint						X	X		0.35
E9	Place the bucket, with the poured paint, in the suction tube of the painting equipment						X	X		0.36
E10	Operator untangles connection cable and plugs in equipment.					X		X		2.05
E11	Hoses, tubes and couplings are checked. All fluid connections are tightened before each use					X		X		1.36
E12	Painter adjusts equipment and nozzle on gun					X		X		3.21
E13	The painter regulates the pressure manually.					X		X		3.17
E14	The painter performs a spray test on buckets of paint to corroborate the effectiveness.					X			X	1.48
E15	Fill the bucket with thinner and place it on the suction tube.					X		X		4.85
E16	The operator disengages the gun trigger safety and fires the gun into a bucket until Thinner flows, then fires for another 10-15 seconds. This is done to remove paint inside the equipment.					X			X	3.07
E17	Operator removes nozzle and nozzle guard from gun and cleans them separately					X		X		3.01
E18	Clean all painted equipment with a cloth				X			X		1.54
E19	Operator cleans and tidies workstation				X			X		3.69

IMPROVEMENT		
Ei	**Elements**	**Time (min)**
E6	Operator opens gallons and pours components (resin, catalyst and diluent) into a bucket.	0.3
E7	The components are manually mixed in the bucket to obtain the paint.	2.2
E8	In a separate bucket the operator strains the paint.	0.32
E9	Place the bucket, with the poured paint, on the suction tube of the painting equipment.	0.3
E10	Operator untangles connection cable and plugs in equipment.	2.05
E11	Hoses, tubes and couplings are checked. All fluid connections are tightened before each use.	1.36
E12	The painter adjusts the equipment and nozzle on the gun.	2.2
E13	The painter regulates the pressure manually.	2.17
E14	The painter performs a spray test on buckets of paint to verify the effectiveness.	1.48
E15	Fill the bucket with thinner and place it on the suction tube.	3.85
E16	The operator disengages the gun trigger safety and fires the gun into a bucket until Thinner flows, then fires for another 10-15 seconds. This is done to remove paint inside the equipment.	3.07
E17	Operario retira la boquilla y el protector de boquilla de la pistola y los limpia por separado.	3.01
E18	Clean all painted equipment with a cloth.	1.54
E19	Operator cleans and tidies workstation.	3.69
	Total	35.34

Figure 6: SMED matrix

5.3.2. Activities standardisation

Finally, the time was recorded with the implementation of the tools, resulting in a reduction of 35.34 minutes. This was achieved thanks to the immediate availability of the main tools for the operator and better organisation in the work area. The results are shown below in Table 5: SMED implementation.

Table 5: SMED Implementation

Current state of the paint change		State after SMED implementation	
			
			

5.4. TPM

For the implementation of TPM in the project, its two fundamental pillars, commonly used by manufacturing sector companies, were employed: autonomous maintenance and planned maintenance. These elements aim to reduce costs and improve results within shorter periods by addressing issues such as unplanned downtime and prolonged machinery repair times. The literature emphasizes the importance of adapting to contexts to achieve successful TPM implementation [32]. Following the production model, the steps represented in Figure 7 were implemented.

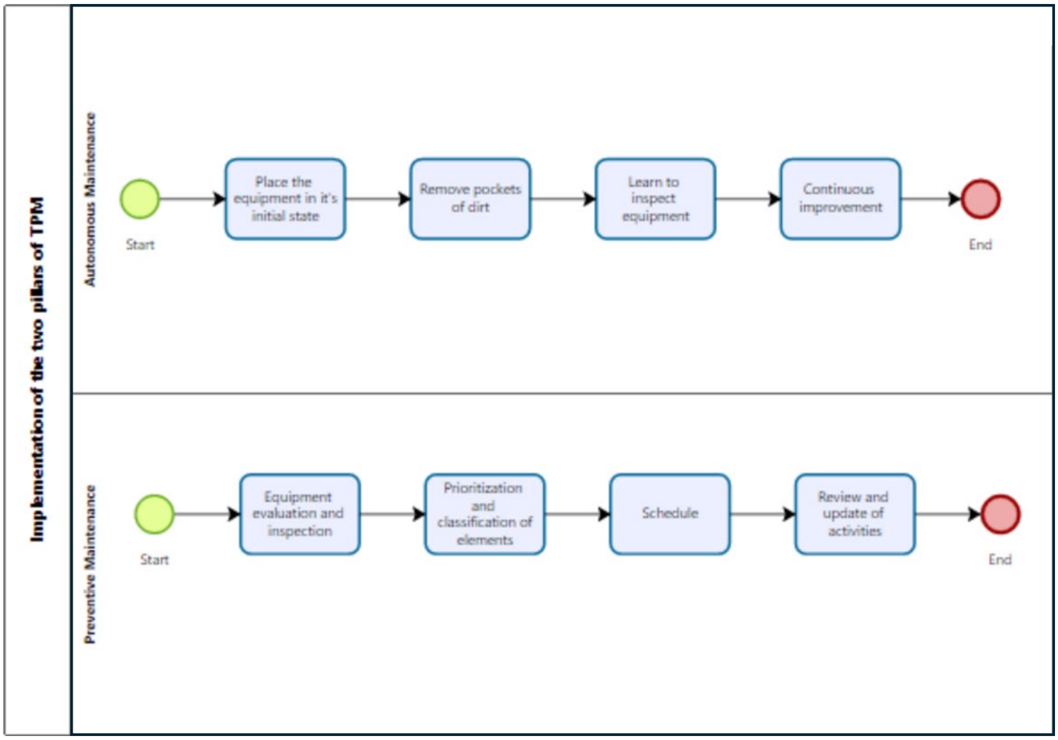


Figure 7: Micro-design TPM

5.4.1. Autonomous maintenance:

The implementation of autonomous maintenance (AM) aims to prevent the deterioration of machines by restoring them to their ideal state and providing the basic conditions to keep them in a good condition. For this, operator involvement in basic maintenance tasks is sought, for which it is essential to develop a maintenance plan tailored to the equipment's needs.

Currently the company faces deficiencies in its cleaning plan, resulting in unplanned downtime caused by failures in the airless painting machines. Therefore, it is crucial to establish simple guidelines to reduce inspection times and to detect potential hidden problems. Since these activities do not require technical skills or specialized knowledge, it is expected that operators could perform them after receiving prior training.

Stages of autonomous maintenance implementation:

Table 6: Implementation of autonomous maintenance

Stages	Activities
1	Increase the knowledge of the operators
2	Cleaning and lubrication procedure
3	Remove dirt and hard-to-reach areas
4	Perform inspection and control
5	Standardise visual maintenance management

Figure 8: Lubrication procedure

5.4.2. Preventive maintenance

In order to deploy the TPM tool, a comprehensive assessment of the existing state of affairs was undertaken. Next a maintenance strategy was established, taking into account the inspection locations and the frequency of each inspection. The maintenance team was equipped with established work procedures to execute these duties. After completing the cleaning tasks, the configuration of fundamental conditions (such as cleaning, lubrication, screw adjustments, and simple maintenance tasks) ensuring the optimal operation of the equipment was carried out.

During the inspection, it was determined that every 1,000 gallons of paint directly affects the proper functioning of the equipment components, impacting both the performance and availability of the equipment, thus affecting its OEE and increasing downtime. Therefore, a periodic maintenance program was implemented to address this issue [33].

Figure 9: Procedure for changing parts of painting equipment

6. DISCUSSION

The research's focus was on enhancing productivity and efficiency while reducing the changeover and setup times for the painting machines in a specialised metalworking company that manufactures square tubes of 7m². The management model contributed significantly through the application of a lean manufacturing methodology that aimed to improve the indicators and achieve process optimisation. Effective resource management becomes crucial in the metalworking industry. In the pre-pilot stage, productivity showed a performance of 1.08 m² painted/M-H, whereas in the post-pilot stage, it increased to 1.18 m² painted/M-H, representing a 10% increment, as shown in Table 7.

Table 7: Indicator results

Indicator	Previous state	Target value	Result: Pilot month of December
Productivity	1.08 m^2/M-H	1.12 m^2/M-H	1.18 m^2/M-H
Setup time	52 minutes	25 minutes	35.34 minutes
MTBF	324.57 minutes	400 minutes	438.17 minutes
MTTR	75.61 minutes	20 minutes	22.68 minutes
Availability	82%	89%	96%
OEE	63.37%	70.00%	78.45%
Paint booth audit	78	125	110
Sandblasting cabin audit	55	125	89.9

On the other hand, the implementation of SMED reduced the changeover and setup times, reflected in a 66.29% reduction (shown by the setup time indicators). Therefore, the identification, classification, and conversion of internal activities into external ones, along with the application and use of quick elements such as the SMED cart, a worktable, and a tool board, allowed process optimisation by standardising these activities. This is shown by a 32.04% reduction in setup time. This improvement aligns with the claims previously made by other authors.

In summary, the application of two pillars of TPM (autonomous and preventive maintenance) resulted in the following achievements in the OEE indicator, with an increase in availability from 0.82 to 0.96, showing a 14% improvement. This yielded an OEE of 78.45% (previously 63.37%), and the 29.63% improvement surpassed the established goal of 15.08% within the three-month time frame. This was demonstrated by a 35% increase in MTBF (mean time between failures) and a 29% decrease in MTTR (mean time to repair).

The 5S methodology aims to reduce clutter and waste and to promote continuous improvement in industrial processes. Its focus is on the reorganisation and standardisation of methods, contributing to waste reduction. In the industrial context, audits revealed improvements ranging from 14.8% to 82.8%. In the present case, the audit improved from 133 to 199.9. This change indicated an increase in efficiency and productivity. In addition, savings in labour costs were achieved through the sale of unused tools and a reduction in input consumption.

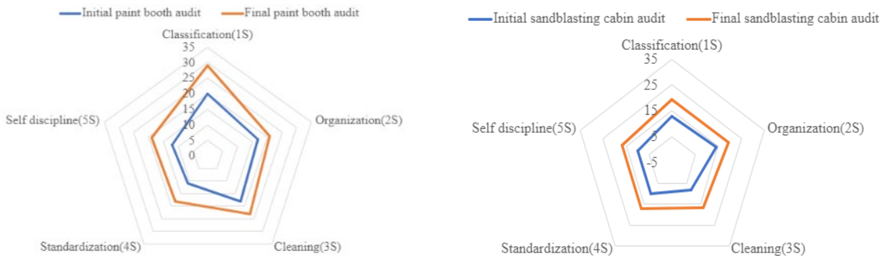


Figure 10: 5S audit in the painting booth and sandblasting cabin

6.1.1. Future research

With the completion of the current research and the intention to disseminate knowledge to other areas of painting and sandblasting in order to contribute to process improvement, several planned improvements can be outlined.

- Develop an evaluation process to determine the feasibility of applying the project proposal to companies of various sizes in the metal-mechanical industry. Regarding medium-sized companies, the project has proven to be viable, as the company in question falls within an intermediate size range.
- It is recommended to conduct periodic training for operators to maintain the standardization of work methods and configuration operations, incorporating the improvements that have been implemented. For future similar research, it would be advisable to conduct a pilot study considering factors such as operator disposition, their learning curve, and resistance to change.
- It is suggested that, before introducing improvements in the organization, a meeting plan be established with all the areas involved in this research. It is also suggested to use the tools in other production lines, adapting them to the reality of each workstation. Likewise, keep operators informed in order to gain their active participation in the improvement proposal and to reduce the risk of resistance to change.

7. CONCLUSION

The lack of available spare parts when needed, combined with the absence of scheduled inspections and a robust set of procedures, is a crucial problem for machinery and equipment efficiency in any company. This issue, identified through detailed analysis, is directly linked to the absence of a maintenance programme. In this regard, the importance of implementing an appropriate plan for autonomous and preventive maintenance is emphasized in order to improve productive times and to optimise maintenance processes – essential aspects for increasing productivity and profitability. Addressing this problem becomes essential to ensure more efficient service and better resource management in the company.

As part of the autonomous maintenance implementation, cleaning tasks were carried out on the machines dedicated to painting with the active participation of specialized operators and supervisors. Then a maintenance plan was designed and executed, covering various activities from improvements to preventive actions and regular equipment maintenance tasks. As a result, it was concluded that the proper application of these methodologies contributed to increasing machine availability from 82.2% to 95.6%.

The implementation of SMED has significantly reduced the change and setup time, achieving a decrease of 66.29%. The use of quick-change elements and the standardization of internal and external activities have been fundamental to this improvement. Moreover, the application of TPM pillars, such as autonomous and preventive maintenance, has led to a 14% increase in availability, along with notable improvements in OEE, MTBF, and MTTR.

In addition, the 5S methodology, focused on reducing clutter and waste, has generated significant improvements in efficiency and productivity, evidenced by audits revealing a 50% increase. In summary, these strategies have led to notable improvements in industrial processes, resulting in cost savings and reduced input consumption.

Initially the company attended to 48 units daily, considering preventive and corrective activities, owing to various unproductive times and extended changeover times. After the validation of both proposals, unplanned stops were reduced, increasing the mean time between failures (MTBF) from 324 minutes to 438 minutes, implying a 73% reduction in unplanned stops. This contributed to the company's productivity by increasing the number of units served to 51 monthly.

The economic viability of the improvement proposal is undeniable, as the investment made is recovered with ample returns, generating a net present economic value of 17.172 PEN and an internal rate of return of 46%. These robust financial indicators underscore the certainty that the investment in this project is not only profitable but also provides significant and favourable returns for those who decide to undertake it.

The arguments presented in the study are solidly supported by a rigorous methodology and detailed empirical data. The implementation of lean manufacturing and TPM tools in an SME in the metalworking sector showed significant improvements in productivity and operational efficiency, thereby validating the theoretical and methodological approaches employed. Although the scope of the study was limited to a specific company, the findings provide valuable information that would be applicable to similar contexts, offering a foundation for future research and practical applications in the field.

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