Improving Productive Efficiency through TPM and SMED in a Peruvian Metalworking SME

Joe William Tirado-Chávez, Joice Corzo-Castro, Gino Viacava-Campos and Jorge Corzo-Chavez
Carrera de Ingeniería Industrial
Universidad de Lima
Lima, Peru
20193527@aloe.ulima.edu.pe, 20192652@aloe.ulima.edu.pe, geiacav@ulima.edu.pe, jacorzo@ulima.edu.pe

Abstract

This article addresses the problem of low efficiency and productivity losses in a small company in the metalworking sector in Peru, which represents 11.2% of the country's manufacturing GDP (Gross Domestic Product), specialized in the manufacture of laboratory equipment for the mining industry. The production of grinding plates with dough was identified as a critical line, presenting low performance reflected in an OEE (Overall Equipment Effectiveness) of 61.9%, well below the industry standard (85%). This inefficiency represented an approximate annual economic loss of USD 65,250. To address this problem, a structured improvement model was implemented based on two key Lean Manufacturing tools: Total Productive Maintenance (TPM), applying autonomous maintenance, preventive maintenance, and training; and the SMED (Single-Minute Exchange of Die) methodology, focused on reducing setup times on CNC lathes. The integration of these methodologies aimed to improve operational efficiency, reduce downtime, and strengthen the company's capacity to respond more competitively to sector demand, with a projected payback period of one year. With an OEE improvement of 69.7%, this improvement proposal represents a key strategy for boosting productivity, reducing operating costs, and ensuring the company's sustainability in the Peruvian metalworking industry.

Keywords
Metalworking, TPM, SMED, OEE, Efficiency.

1. Introduction
Today, the metalworking industry plays a fundamental role in the Peruvian economy, supplying components and equipment to key productive sectors such as manufacturing, mining, agriculture, and construction (Oficina General de Evaluación de Impacto y Estudios Económicos, 2024). However, increasing market competitiveness has forced companies, particularly small and medium-sized enterprises (SMEs), to seek higher levels of efficiency and cost reduction without compromising product quality (Jara et al., 2023).

According to the Peruvian Ministry of Production, the metalworking sector contributes approximately 11.2% to the manufacturing gross domestic product and is largely composed of SMEs, which frequently face operational inefficiencies such as unplanned downtime, reprocessing, and a lack of standardized production processes (Santos et al., 2023). These limitations reduce productivity and weaken the competitive position of companies in both domestic and international markets (Arbieto et al., 2020).

Many of these inefficiencies are associated with inadequate maintenance practices, long setup times, and an organizational culture focused primarily on corrective actions rather than preventive and continuous improvement

strategies (Cordova-Matias et al., 2023). In this context, Lean Manufacturing methodologies have emerged as effective approaches to improve operational performance. Among these, Total Productive Maintenance (TPM) and Single-Minute Exchange of Die (SMED) stand out due to their direct impact on equipment availability, reliability, and time reduction (Singh et al., 2022; Osco et al., 2023).

This study proposes and validates a combined TPM and SMED improvement model applied to a small Peruvian metalworking company. The research addresses a documented gap in literature, as most previous studies focus on large-scale industries, while empirical evidence of the joint application of these tools in SMEs remains limited. Through the implementation of planned maintenance, autonomous maintenance with operator training, and SMED on CNC lathe setups, this research evaluates the impact of the proposed model on Overall Equipment Effectiveness (OEE), operational efficiency, and economic performance.

1.1. Objectives
Increase the efficiency of the production process of grinding plates in a metalworking company through the implementation of TPM and SMED.

1.1.1. Specific objectives
Reduce reprocessing due to oven temperature failures by applying planned maintenance and implementing training programs for time and operation control. Reduce rework due to failure of the welding machine calibration method by applying planned maintenance. Reduce unproductive set up times on CNC lathes by applying SMED.

2. Literature Review
2.1. Main causes of low efficiency in the metalworking sector
Within the metalworking sector, the scope of economic development in countries like Peru is seen as a key point, as this sector supplies industries such as construction and mining. According to the Ministry of Production, the sector is a point above the manufacturing sector, accounting for a large part of industrial employment (Ministry of Production, 2023). A large proportion of companies in this sector are SMEs, which present limitations related to low operational specialization, limited access to continuous improvement tools, and a lack of modern technology. Among the main difficulties within this sector are downtime, constant reprocessing within production time and low equipment availability, which affects the company's competitiveness against more efficient markets (Santos et al., 2023)

2.2. Level of efficiency in the metalworking sector
In industrial settings, efficiency refers to the optimal use of available resources to achieve maximum operational performance. It is commonly associated with factors such as equipment availability, cycle times, production quality, and delivery compliance.

According to Singh and Gurtu (2022), overall efficiency should be measured using indicators such as Overall Equipment Effectiveness (OEE), which integrates availability, performance, and quality. However, many metalworking companies operate with OEE levels below the optimal benchmark of 85% due to the lack of structured maintenance, long setup times, and disorganization within the plant (Quiroz-Flores et al., 2023).

2.3. TPM in the metalworking sector

Total Productive Maintenance (TPM) was originally developed in Japan as a systematic approach to maximize equipment effectiveness throughout its entire life cycle. Nakajima (1988), recognized as the pioneer of TPM, established it as a methodology based on eight pillars aimed at eliminating losses, improving reliability, and actively involving operators in maintenance activities. In metalworking environments, TPM has proven to be especially effective in reducing unplanned downtime, improving Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR), and fostering a culture of continuous improvement (Cordova-Matias et al., 2023).

Planned maintenance, autonomous maintenance, and staff training generate significant improvements in operational efficiency. Huertas-Reyes et al. (2022) applied TPM in a Peruvian metalworking company, achieving improved order delivery performance and a significant reduction in downtime, highlighting the relevance of this methodology for small and medium-sized enterprises.

2.4. SMED Application

The SMED methodology was originally developed by Shingo (1985) as a systematic approach to reduce setup times by separating internal and external activities and streamlining changeover processes.

The SMED methodology enables the efficient minimization of changeover times on machines and production equipment by distinguishing between internal and external activities. This approach is particularly relevant in the metalworking industry, where long setup times directly affect production efficiency and equipment availability.

Within the metalworking sector (Carlos Quiroz-Flores & Fidel Collao-Diaz, 2022), it has been verified that the implementation of SMED considerably reduces setup times by more than 30%, achieving increased production and decreasing unproductive and delay times. In addition, an increase in production schedules was recorded after restructuring the change process through the use of the SMED tool (Huertas-Reyes et al., 2022).

The selection of Total Productive Maintenance (TPM) and Single-Minute Exchange of Die (SMED) was based on the specific operational constraints identified in the metalworking production line. The main sources of inefficiency were related to frequent equipment failures, long repair times, and extended setup durations, directly affecting equipment availability and production continuity. While other Lean tools such as 5S, Kanban, or Value Stream Mapping contribute to organizational order and flow optimization, TPM and SMED directly target the root causes of downtime and changeover losses, making them more suitable for addressing availability and performance losses reflected in the Overall Equipment Effectiveness (OEE) indicator.

3. Methods

Figure 1 illustrates the conceptual model of the proposed solution, integrating TPM and SMED as complementary methodologies to reduce equipment-related losses and setup times, thereby improving Overall Equipment Effectiveness (OEE).
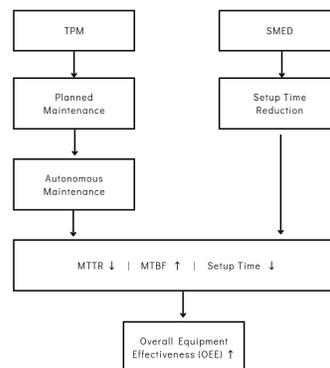

Figure 1. Conceptual model linking TPM and SMED to OEE improvement

3.1 Contribution and Proposed Solution Model

The proposed model includes the following stages: the first involves analyzing the factors affecting efficiency in

the production line for dough-based grinding plates, highlighting long setup times on the CNC lathe, reprocessing resulting from incorrect calibration during heat treatment, and unplanned downtime due to lack of maintenance. To achieve this, a failure analysis, time study, and evaluation of the economic impact associated with these inefficiencies are performed. Likewise, the OEE analysis showed that the production line reaches only 61.9% compared to the 85% industry benchmark, reflecting a 23.1% technical gap and confirming the need to implement TPM and SMED to close this difference.

The reference value of 85% OEE corresponds to a world-class manufacturing commonly used in large-scale and highly standardized industrial environments. However, in the context of small and medium-sized metalworking enterprises, this value should be interpreted as an aspirational target rather than an initial operational condition, SMEs typically face limitations related to maintenance maturity, process standardization, and resource availability, which justify a progressive and staged approach toward closing the efficiency gap (Figure 2).
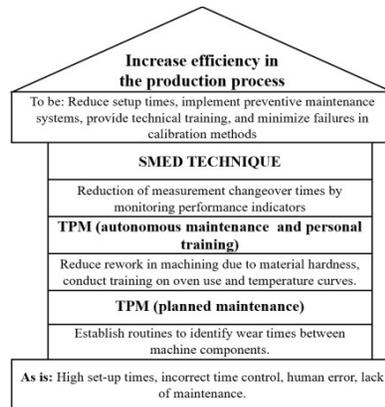

Figure 2. Proposed Solution Model

Economic Impact Assessment

The estimated annual economic loss of USD 65,250 was determined through an economic impact assessment focused on operational inefficiencies in the grinding plate production line. The assessment compared the current production scenario with an ideal scenario in which the Overall Equipment Effectiveness (OEE) is improved from 61.9% to 85%. In the current scenario, the company produced 200 units of grinding plates, with an average unit price of USD 1,440. The total revenue from grinding plates in 2023 was USD 288,000. However, under the ideal scenario with improved OEE, production increased to 275 units, yielding total revenue of USD 396,000. This resulted in a lost revenue of USD 108,000 due to suboptimal OEE performance.

To assess the economic impact, the total income of the company, which includes all products sold, was considered. The total income in 2023 was USD 1,259,970, and the loss due to the inefficient production process represented 8.57% of total income.

The costs per unit produced include USD 350 for direct costs and USD 220 for overhead, which covers energy, labor, consumables, and other indirect expenses. In the current scenario, total costs amounted to USD 70,000, with an additional USD 44,000 in operating expenses. In the ideal scenario, with higher production volume, the total costs and expenses increased to USD 96,250 and USD 60,500, respectively.

Therefore, the profit in the current scenario for 2023 was USD 174,000. In the ideal scenario, the profit would be USD 239,250, resulting in a difference of USD 65,250, which represents 9.19% of the total profit for the company in 2023. This economic loss can be directly attributed to operational inefficiencies, including extended downtime, long setup times, and reprocessing of parts due to incorrect heat treatment.

3.1.1 Component 1:TPM - (Planned Maintenance)

TPM focuses on the structured planning of maintenance activities to ensure equipment availability, minimize unexpected downtime, and extend the lifespan of productive assets. In this research, it was specifically applied to the welding machine, a key piece of equipment in the welding of dough, whose operation is critical to maintaining continuous flow on the production line. During the initial diagnosis, recurring failures were identified associated

deterioration of power cables, obstruction of the ventilation system, and wear on the welding gun, which caused operational delays, loss of quality, and risks to the operator.

To address this situation, a monthly preventive maintenance schedule was designed and implemented, structured into weekly tasks of visual inspection, cleaning, checking electrical connections, adjusting moving parts, and verifying the proper functioning of the cooling system. This schedule was accompanied by the development of standardized inspection forms, which are completed by both the operator and specialized maintenance personnel, allowing for the recording of potential failures, intervention dates, and corrective actions taken.

This intervention not only reduced the frequency of unscheduled downtime but also strengthened maintenance traceability through documented evidence. Furthermore, by empowering operators to monitor equipment status, a culture of shared responsibility and operational discipline was fostered. As a result, an improvement in the welding machine's technical availability was observed, directly contributing to an increase in OEE and the sustainability of the continuous improvement model implemented at the plant.

3.1.2 Component 2: TPM – (Autonomous maintenance and staff training)

The combination of TPM pillars 2 and 7 aims to involve operators in both basic machine maintenance and technical training, promoting a culture of shared responsibility and continuous improvement. This strategy seeks to prevent frequent failures, reduce human error, and improve the quality of the production process.

On the one hand, autonomous maintenance was implemented on the heat treatment machines, particularly the furnace, which suffered from recurring failures due to residue accumulation, wear and tear from misuse, and electrical problems. To address this problem, daily inspection sheets, shift cleaning forms, and visual labels identifying critical areas were designed. In addition, basic lubrication and adjustment tasks were assigned to operating personnel, with the goal of anticipating failures and reducing dependence on corrective maintenance.

On the other hand, the training pillar addressed one of the root causes of reprocessing: incorrect heat treatment due to a lack of technical knowledge. A training plan was implemented focusing on three pillars: proper use of the furnace, the concept of autonomous maintenance, and the importance of using protective equipment at work. These sessions allowed the operator to understand the impact of their work on the final hardness of the parts, thus improving machining results and avoiding excessive hardness during machining.

The synergy between both pillars allowed not only to increase the availability of equipment, but also to empower the operator as a key agent in product quality, ensuring the sustainability of the implemented improvement model.

3.1.3 Component 3: SMED (Single-Minute Exchange of Die)

The SMED methodology focuses on reducing machine changeover times, especially in processes where setups are lengthy and affect operational availability. This technique classifies changeover activities into internal (performed with the machine stopped) and external (performed with the machine running), with the goal of transforming the largest number of internal tasks into external ones, eliminating unnecessary activities, and standardizing the remaining ones.

In this study, SMED is applied to CNC lathe operations, where machining process times averaged 7 hours and 9 minutes. Through data collection, direct observation, and activity diagramming, tools such as setup checklists, visual guides, and preset templates were designed, which led to a reduction of 1 hour and 22 minutes per grinding plate. This improvement directly impacts efficiency by reducing downtime and increasing machine availability.

The implementation of SMED is complemented by a validation phase through a pilot test, which allows evaluating the effect of the new setup times on monthly and annual production capacity, in relation to the OEE indicator.

4. Data Collection

The improvement proposal was validated directly in the metalworking company's actual operations, with formal authorization from management and coordination with operating personnel. For its implementation, the corresponding permits were obtained, and a schedule of weekly plant visits was established, allowing for the collection of technical information, evaluation of ongoing results, and the introduction of viable improvements.

Validation was based on the monitoring of key indicators such as mean time between failures, mean time to repair, and setup times.

The intervention was structured into three components: Component 1, related to planned maintenance, was developed as a pilot test on the welding machine, where electrical faults and failures in the electrical components were identified. Component 2, focused on autonomous maintenance with technical training for the operator, was also applied as a pilot test, in this case on the heat treatment furnace. It is based on routine inspections and lubrication, with the aim of reducing reprocessing of high-hardness parts. Finally, Component 3, linked to the reduction of setup times through the SMED methodology, was formally implemented on the CNC lathes, given its direct impact on downtime.

This combined pilot testing and implementation strategy allowed the improvement model to be validated based on measurable results, demonstrating its applicability and sustainability in the metalworking production environment. As part of the diagnostic, key production performance indicators were evaluated. OEE (Overall Equipment Effectiveness) recorded a value of 61.9%, reflecting deficiencies in process availability, performance, and quality. Furthermore, the average setup time was 7.16 hours, revealing significant inefficiencies during transitions between production batches.

In terms of operational reliability, the MTBF (Mean Time Between Failures) indicator was 44.44 hours, which represents a relatively short interval between failures, while the MTTR (Mean Time to Repair) reached 2.89 hours, indicating that corrective interventions require long recovery times. These results reinforce the need to implement preventive and autonomous maintenance strategies, as well as methodologies that reduce downtime and optimize the use of available resources (Table 1).

Table 1. Baseline production performance indicators of the grinding plate production line

Indicator	Unit	Initial situation
OEE	%	61.9%
Time of reduction of changes	Hours	7.16
MTBF	Hours	36.37
MTTR	Hours	2.89

4.1. Pilot Test Component 1: TPM – (Planned Maintenance)

The implementation of planned maintenance was developed as a pilot test on the welding machine, with the goal of reducing mean time to repair (MTTR) and preventing recurring failures. A 15-month period (January 2024–March 2025) was analyzed, recording a total of 247.34 hours of downtime due to failures, with an average of 5.87 events per month (Figure 3).

Figure 3. Repair time before planned maintenance implementation (January 2024 – March 2025)
This Figure 3 shows the months with the greatest impact on repair times, which motivated the development of the planned maintenance plan.

The main problems identified included amperage reading errors, blown internal fuses, an unresponsive LCD screen, and ground faults. A heavy reliance on corrective maintenance was evident. Based on this, a machine life sheet, preventive and planned maintenance forms, and personnel were trained in inspection, cleaning, and calibration tasks. The monthly variation allows us to observe how the behavior of the indicator progressively stabilized after implementation (Figure 4).
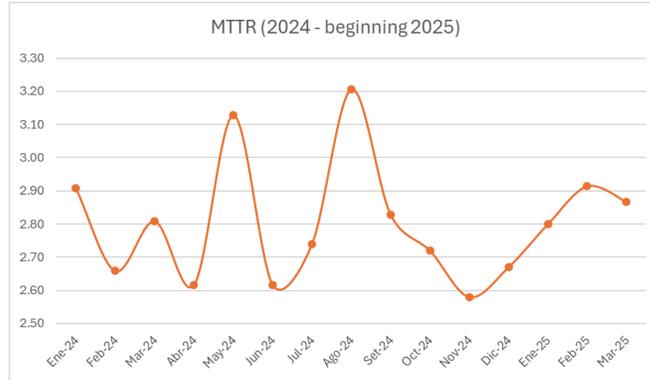

Figure 4. Repair time after planned maintenance implementation (January 2024 – March 2025)

Figure 4 shows a reduction and stabilization of repair times after the implementation of the planned maintenance program, indicating an improvement in equipment availability and maintenance effectiveness compared to the pre-implementation period.

The planned maintenance program was supported by a structured implementation format that enabled formal recording of machine status and maintenance activities. Its execution included the design of a weekly task schedule, the use of physical records, and checklists posted on the plant floor to facilitate tracking and traceability. Additionally, technical training was provided to reinforce the consistent and periodic completion of maintenance activities.

4.2. Pilot test Component 2: TPM – (Autonomous maintenance and staff training)
The pilot test for component 2 was carried out in a heat treatment furnace, implementing autonomous maintenance and training of TPM personnel. The objective was to reduce unplanned failures, improve equipment reliability, and extend its service life. The key indicator was MTBF (mean time between failures).

During the pre-assessment (January 2024–March 2025), 58 failures were identified, with a monthly average of 4.8 (Figure 5).
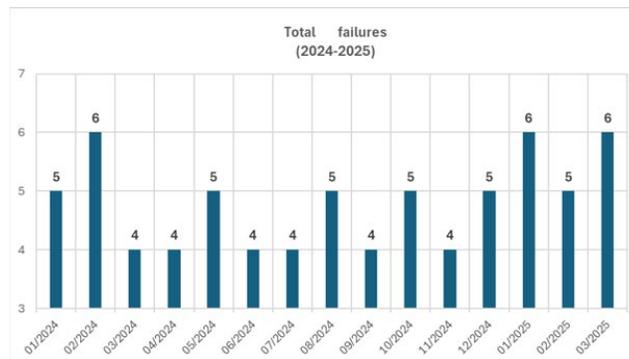

Figure 5. Total failures before autonomous maintenance implementation (January 2024 – March 2025)

Data on the date, duration, and type of failure were recorded. Among the most frequent failures were heater wear, control system failures, refractory brick detachment, temperature sensor errors, and gas obstruction or leaks.

Figure 6 shows the variability of the Mean Time Between Failures (MTBF) prior to the implementation of autonomous maintenance, evidencing unstable operating conditions and frequent interruptions in the production process.
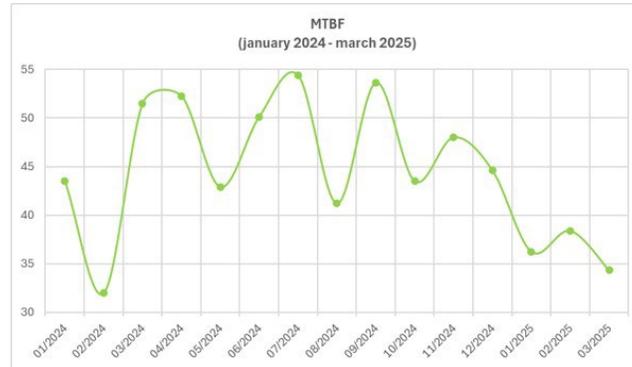

Figure 6. MTBF before autonomous maintenance implementation (January 2024 – March 2025)

To initiate the improvement process, a machinery lifecycle report was created, defining the furnace's initial conditions. Subsequently, basic and comprehensive maintenance training was provided, including theory, signed attendance, and assessment of understanding through surveys.

Once the staff was trained, specific preventive maintenance tasks were defined, establishing their frequency and those responsible. To facilitate traceability, physical activity logs were implemented. In addition, critical furnace sensors were defined, which are essential for monitoring its continuous operation.

4.3. Implementation Component 3: SMED (Single-Minute Exchange of Die)

The SMED methodology was implemented on the CNC lathe with the goal of reducing changeover times and optimizing efficiency in machining operations. To achieve this, total setup time was used as a key indicator.

Initially, a time-tracking process was performed on the turning process, identifying critical activities and revealing a high proportion of internal activities due to the lack of organized tools in the work area. Twenty-five internal activities were identified compared to 20 external activities, reflecting opportunities for improvement.

In response, a list of essential tools to have in the work area was developed to facilitate the pre-configuration of activities and avoid unnecessary interruptions (Table 2).

Table 2. Standardized set of tools in the CNC lathe work area

List of Tools in Work Area				
Type	*Desc.*	*Q*	*Place*	*State*
Torx wrench	All sizes	1	Workplace	Ready to use
Allen wrench	All sizes (Complete kit)	1	Workplace	Ready to use
Laina	M 10cm x 2cm - different th	10	Workplace	Ready to use
Inserts	-	6	Workplace	Ready to use
Calibrator	up to 1000mm	1	Workplace	Ready to use
Instructions	Operation Guide	2 copies	Workplace	Ready to use
Plans	Parts measurements	2 copies each	Workplace	Ready to use
Usb	Back-up programs	1	Workplace	Ready to use
Refrigerant	To cool the blade	3 liters	Workplace	Ready to use

Table 2 summarizes the standardized set of tools required in the CNC lathe work area, which facilitated the

conversion of internal setup activities into external ones and reduced unnecessary operator movements.

Subsequently, a verification format was implemented to distinguish which tasks could be moved from internal to external, and controls were applied to evaluate its effectiveness. Prior to the implementation, all process activities were classified, resulting in 20 external and 25 internal activities. Subsequently, following the improvement measures, the distribution shifted to 30 external and 15 internal activities, indicating an optimization in task organization.

Based on this classification, a more robust time-tracking process was conducted with 20 measurements between April and May 2025, covering the key components: plate, lid, and dough. The larger sample size allowed for more representative data on the new process performance.

5. Results and Discussion

The results presented in this section are based on operational data collected during the pilot tests conducted on the production line. Maintenance indicators (MTTR and MTBF) were calculated using average values obtained from records collected over a 15-month period (January 2024–March 2025). Setup time results for the SMED implementation were obtained from 20 repeated measurements conducted between April and May 2025. This data collection approach ensured representative and reliable performance evaluation.

5.1 Numerical Results

During the implementation phase, a substantial improvement was observed in maintenance performance indicators. The MTTR decreased from 2.89 to 1.08 hours, equivalent to a 62.6% reduction. Moreover, seven detected failures were resolved without interrupting the production flow, confirming the effectiveness of the applied approach (Table 3).

A life sheet was created for the equipment, complemented by a preventive maintenance plan with weekly checklists for inspection, cleaning, electrical verification, and cooling system checks.

Operators were trained to complete the records and monitor the status of the welding machine. This strengthened traceability and discipline on the plant floor, contributing to the sustainability of the maintenance model.

Table 3. MTTR comparison before and after planned maintenance implementation

Initial MTTR (Feb – Mar)	Final MTTR (Apr – May)	Improvement
2.89	1.08	1.81

In addition, the MTBF increased from 36.37 to 88.56 hours, representing a 144% improvement. This result highlights the enhanced operational continuity of the furnace, with a significant reduction in the frequency of critical interruptions (Table 4).

Inspection formats and visual labels were introduced to facilitate operator participation in daily checks, cleaning, lubrication, and adjustment of critical areas. In parallel, training sessions were carried out to improve the correct use of the furnace, the principles of TPM, and the importance of using personal protective equipment. Physical activity logs and the definition of critical sensors ensured continuous monitoring. These actions empowered the operator as a quality agent, reduced reprocessing due to incorrect hardness, and significantly increased equipment reliability.

Table 4. MTBF comparison before and after autonomous maintenance implementation

Initial MTBF (Feb – Mar)	Final MTBF (Apr – May)	Improvement
36.37	88.56	52.19

Finally, the implementation of the SMED methodology reduced the average setup time from 7.16 to 5.78 hours,

achieving a 19.26% improvement (Table 5). This reduction was mainly driven by the reorganization of tools, the classification of tasks, and the optimization of operational sequences, as illustrated in Figure 7.

The activities were classified into 25 internal and 20 external before implementation, then optimized to 15 internal and 30 external. A standardized kit of tools was arranged in the work area, along with visual guides and setup checklists. A pilot with 20-time measurements validated the improvements, confirming a consistent reduction in changeover time.

Table 5. Setup time comparison before and after SMED implementation

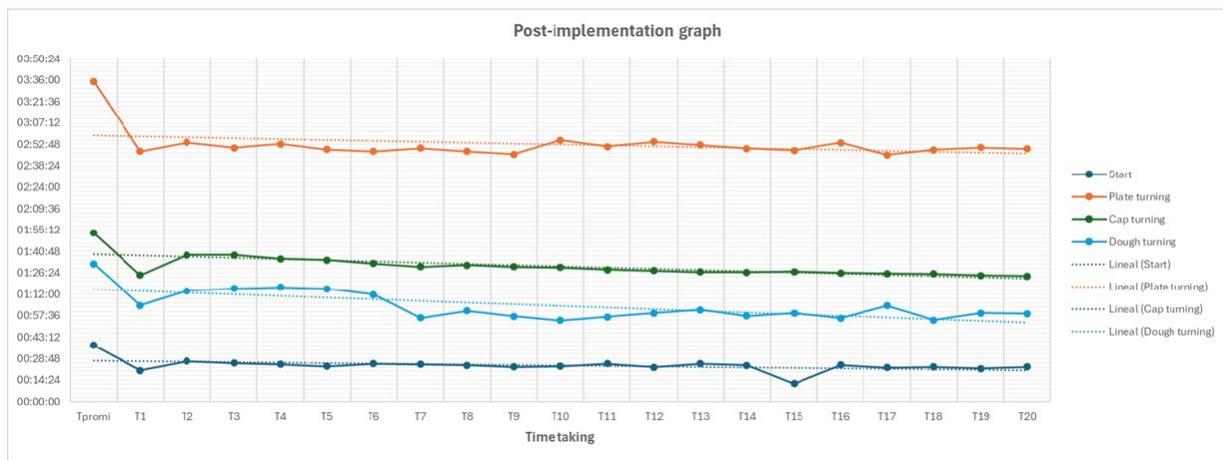| Initial change times	Times of final change	Improvement
7.16	5.78	1.38

Figure 7. Post – Implementation SMED graph

The technical improvements achieved through the application of TPM and SMED had a direct economic impact on the production line. The reduction in unplanned downtime, the increase in equipment reliability, and the decrease in setup times resulted in higher productive availability and lower reprocessing levels. As a consequence, the company achieved an estimated annual profit improvement of USD 65,250, confirming that the operational gains observed are not only technically significant but also economically relevant for the sustainability of the organization.

An important factor influencing the effectiveness of the proposed improvement model was change management and operator acceptance. During the initial stages of implementation, a degree of resistance was observed, mainly associated with the introduction of new routines for inspection, data recording, and autonomous maintenance activities.

This resistance was progressively reduced through targeted training sessions, clear communication of the objectives and benefits of TPM and SMED, and the active involvement of operators during pilot tests. By participating directly in maintenance tasks, setup standardization, and performance monitoring, operators developed a greater sense of ownership over equipment condition and product quality. As a result, operator engagement became a key enabler for sustaining the improvements achieved in OEE, MTBF, and setup time reduction.

5.2 Proposed Improvements
Practical recommendations include strengthening preventive and autonomous maintenance routines, ensuring continuous training programs for operators, and expanding the application of SMED to other machines in the production line. Likewise, it is recommended to address aspects identified but not intervened in this study, such as the elimination of unnecessary operator movements and the organization of the work area, which represent additional sources of waste and affect both safety and process efficiency.

For future research, it is suggested to apply SLP (Systematic Layout Planning) and the 5S methodology to reduce unnecessary movements within the plant. In addition, the use of 5S and KANBAN is recommended as strategies to improve order, cleanliness, and visual management in the workplace, thus fostering a culture of continuous improvement and enhancing operational efficiency.

5.3 Validation
With the implementation described, the results of the improvement proposal were obtained, which show the following results:

Regarding the TPM (planned maintenance) component, the MTTR of the welding machine was reduced from 2.89 to 1.08 hours, which represents a decrease of 62.6%, reflecting a significant improvement in the response capacity to failures and in the operational availability of the equipment. In the case of the TPM (autonomous maintenance and training) component, the MTBF of the heat treatment furnace was increased by 36.37 to 88.56 hours, equivalent to an improvement of 52.19 hours. This gap indicates a reduction in the failure rate.

Finally, with the SMED component, setup times on the CNC lathe were optimized, going from 7.16 hours to 5.78 hours, representing a 19.26% reduction, improving the efficiency of reference changeovers. Overall, the application of these tools had a positive impact on the company's operational efficiency, achieving an increase in OEE from 61.90% to 69.7%.

6. Conclusion
This study addressed the problem of low operational efficiency in a Peruvian small and medium-sized metalworking enterprise by evaluating the impact of Total Productive Maintenance (TPM) and Single-Minute Exchange of Die (SMED) methodologies. The study evaluated whether the combined implementation of TPM and SMED could significantly improve equipment performance, reduce downtime, and enhance overall operational efficiency in a metalworking production line.

The results confirm that the research objective was successfully achieved. The coordinated application of planned maintenance, autonomous maintenance with operator training, and SMED led to substantial improvements in equipment availability, performance, and quality, which were reflected in a significant increase in Overall Equipment Effectiveness (OEE) from 61.90% to 69.7%. These operational improvements were accompanied by a measurable economic benefit, resulting in an estimated annual profit improvement of USD 65,250, demonstrating the economic viability of the proposed improvement model for small and medium-sized enterprises in the metalworking sector.

Despite these positive outcomes, this study presents certain limitations that should be considered when interpreting the results. The analysis was conducted in a single metalworking company and focused on specific critical machines within the production line, which may limit the generalization of the findings to other industrial contexts or larger-scale manufacturing environments. In addition, the evaluation period was limited to the duration of the pilot tests, and external factors such as demand variability, market conditions, and long-term equipment aging were not explicitly considered.

Future research could expand the scope of this study by integrating complementary Lean Manufacturing tools such as 5S and Systematic Layout Planning (SLP) to further improve workplace organization and material flow. Additionally, extending the TPM maturity model across the entire production facility and incorporating digital TPM approaches, including IoT-based condition monitoring and predictive maintenance, would allow the evaluation of the long-term sustainability and scalability of the proposed improvement model.

References
Arbieto, M., Vásquez, J., Altamirano, E., Álvarez, J., and Marcelo, E., "Lean Manufacturing tools applied to the metalworking industry in Perú," *Proc. 2020 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI 2020)*, 2020, doi: 10.1109/CONIITI51147.2020.9240362.

Quiroz-Flores, J. C., and Collao-Diaz, M. F., "Production model using Lean Manufacturing tools applied in a continuous production line of a Peruvian metalworking company," *Proc. 2022 Congreso Internacional de Innovación y Tendencias en Ingeniería (CONIITI 2022)*, 2022, doi: 10.1109/CONIITI57704.2022.9953698.

Cordova-Matias, B., Palacios-Molina, M., and Flores-Perez, A., "Model to increase compliance with deliveries of metal structures using TPM tools in a metalworking company," *Proc. 9th Int. Conf. on Innovation and Trends in*

Engineering (CONIITI 2023), 2023, doi: 10.1109/CONIITI61170.2023.10324027.

Coyuntural Sector Manufactura, *Resultados del Desempeño de la Industria Manufacturera Año 2023*, n.d. [Online]. Available: producempresarial.pe

Huertas-Reyes, A., Quispe-Huerta, S., Leon-Chavarri, C., and Velasquez-Costa, J., "Increased efficiency of a metalworking SME through process redesign using SMED, Poka Yoke and work standardization," *Proc. LACCEI Int. Multi-Conf. for Engineering, Education and Technology*, Dec. 2022, doi: 10.18687/LEIRD2022.1.1.69.

Jara, B., Calderon, S., and Avalos-Ortecho, E., "Application of Lean Manufacturing to increase productivity of a company in the metalworking sector," *Advances in Transdisciplinary Engineering*, vol. 35, pp. 740–753, 2023, doi: 10.3233/ATDE230102.

Oficina General de Evaluación de Impacto y Estudios Económicos, *Análisis Sectorial: Desempeño e Importancia de la Industria de Metalmecánica*, 2024. [Online]. Available: producempresarial.pe

Osco, J. C., Ricce, M. C., Yildiz, O., Ipince, D. A., and Alvarez, J. C., "Operations management model based on 5S, TPM, and SMED to increase the effectiveness of equipment in a plastics company," *Proc. 9th Int. Conf. on Innovation and Trends in Engineering (CONIITI 2023)*, 2023, doi: 10.1109/CONIITI61170.2023.10324211.

Quiroz-Flores, J. C., Cancho-Alvaro, B., and Rodriguez-Arcos, J., "Increased machine efficiency through a production model integrating Lean tools and the ADKAR model in an SME of the metalworking industry," *Proc. LACCEI Int. Conf.*, 2023, doi: 10.18687/LACCEI2023.1.1.121.

Santos, E., Lima, T. M., and Gaspar, P. D., "Optimization of the production management of an upholstery manufacturing process using Lean tools: A case study," *Applied Sciences*, vol. 13, no. 17, 2023, doi: 10.3390/app13179974.

Shingo, S., *A Revolution in Manufacturing: The SMED System*, Productivity Press, 1985.

Singh, R. K., and Gurtu, A., "Prioritizing success factors for implementing total productive maintenance (TPM)," *Journal of Quality in Maintenance Engineering*, vol. 28, no. 4, pp. 810–830, 2022, doi: 10.1108/JQME-09-2020-0098.

Singh, S., Agrawal, A., Sharma, D., Saini, V., Kumar, A., and Praveenkumar, S., "Implementation of total productive maintenance approach: Improving overall equipment efficiency of a metal industry," *Inventions*, vol. 7, no. 4, 2022, doi: 10.3390/inventions7040119.

Biographies

Joice Corzo holds a bachelor's degree in industrial engineering from the University of Lima and currently works in the Supply Department of a mining company, where she contributes to optimizing logistics and procurement processes with a focus on operational efficiency and supply chain sustainability. She has developed projects related to continuous improvement, productivity analysis, and industrial management through the application of engineering methodologies. In addition, she has participated in volunteer and social initiatives dedicated to supporting children and families in vulnerable situations. Her profile combines strong technical training with a deep human and social commitment, promoting responsible engineering aimed at sustainable development and the well-being of the community.

Joe Tirado is a graduate in Industrial Engineering from Universidad de Lima. He currently works at a metalworking company in the Continuous Improvement area, where he is responsible for time data collection, process optimization, and the enhancement of operational efficiency. He has completed specialized courses in Industry 4.0 in Germany, gaining valuable knowledge in automation, digitalization, and advanced industrial technologies. Following the COVID-19 pandemic, he participated in volunteer programs supporting vulnerable communities, reflecting his strong sense of social responsibility and commitment to positive impact. He is a proactive and analytical professional with a continuous improvement mindset and a strong motivation to keep learning, innovating, and contributing to industrial development.

Gino Viacava Campos is currently a professor in industrial engineering career at Universidad de Lima. He holds a Master in Operations and Logistics from Universidad Peruana de Ciencias Aplicadas (UPC) (Perú) and is Industrial Engineer from the Universidad de Lima (Perú). He has experience in industrial and service companies to improve productivity, development of business models and structure compensation systems. He has worked in human resources area,operations and logistics areas of a transnational company, locally and overseas. As consultant he has experience with construction, manufacturing, services, mining, commercial, finance and education sector. His main research interests are lean manufacturing, master production schedules, logistics, compensation systems for small and medium-sized enterprises

Jorge Antonio Corzo-Chavez is currently a professor in industrial engineering career at Universidad de Lima, chief executive officer at Conquista Lab, and associate consultant at Manpower Group for multinational companies. He holds a Master in Business Administration from Universidad ESAN (Perú), a Master in Marketing Science from ESIC Business & Marketing School (Spain) and is Industrial Engineer from the Universidad de Lima (Perú). He has experience in advising industrial and service companies to improve productivity and development of business models. He has worked in areas of entrepreneurship and innovation, marketing and commercial for the construction, metalworking, mining, services, and education sectors. His main research interests are lean manufacturing, master production schedules, logistics, machine learning, and innovation for small and medium-sized enterprises