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Increased Productivity through SMED and TPM in a Metalworking SME: An Empirical Investigation in the Peruvian Industry

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Abstract

The objective of this study is to increase productivity and availability to improve profitability and competitiveness in the metal-mechanic sector. The case study is based on the implementation of TPM and SMED in an aluminum bolt production process in a Peruvian SME of the metal-mechanic sector where the current productivity is 9.23 units/man-hour. SMED transforms internal activities by external ones in order to reduce the production cycle time. TPM autonomous/preventive makes it possible to apply a constant scheduled maintenance that improves and facilitates the activities performed by the machine in order to reduce operator effort and increase OEE. The implementation was validated through a pilot test that lasted 4 months where the results obtained were: 38.40% improvement in OEE, cycle time reduction from 6.51 minutes to 4.52 minutes, 16.93% increase in availability, MTBF increase from 12.5 to 22.43 hours/failure, MTTR reduction from 6.4 to 4.57 hours/failure, 30% performance improvement and productivity increase to 13.28 units/man-hour.

Keywords
Productivity, SMED, TPM, SME and Metalworking.

1. Introduction
Currently, in the year, the manufacturing industry in Peru contributes 12.5% of the national GDP reaching a figure of S/. 6243 million soles (Ministerio de la producción 2024). Within the manufacturing industry is the metal-mechanic sector which, from the year 2019 to the year 2023, the number of companies has increased from 63439 to 72711 companies being mostly SME which are equivalent to 99.5%. (Oficina General de Evaluación de Impacto y Estudios Económicos 2024) The present work takes as a case study an SME of the metal-mechanic sector that presents a productivity of 9.2 units/man-hour, being lower than 16.6 units/man-hour, presenting a variation of 44.58%, which is the productivity of another representative SME of the same sector (Cairo et al. 2023). One way to improve productivity is by applying SMED, as in the case of the increase of this indicator from 0.38 to 1.16 6 units/man-hour in the cutting area of a textile industry (Alanya et al. 2024). SMED is also applicable in other sectors such as metalworking, where productivity increased by 19% (Jara et al. 2023). On the other hand, TPM helps to increase productivity as in the case of a shoe manufacturing company which increased from 12.57 to 18.83 pairs of shoes/Man-Hours (Mendoza et al. 2023). TPM, besides contributing to improve the efficiency of equipment and machines, helped to improve productivity from 2.39 to 2.50 soles sold/soles invested, a variation of 4.6% (Vasquez et al. 2023). After a follow-up of 4 months in the case study and after the application of SMED and TPM tools, the productivity percentage increased by 30.5%. This scientific article has an introduction, state of the art, results, discussions and conclusions.

1.1 Objectives
The main objective of this research article is to increase by 44.5% the productivity of an aluminum bolt production process in an SME through the application of SMED and TPM tools. Additionally, one of the most relevant specific objectives established with the implementation is to increase the availability of the machines in the company.

2. Literature Review
2.1 TPM
Most of the companies in the metal-mechanic sector in Peru have different deficiencies and complications in their production systems. To counteract these deficiencies, tools such as preventive/autonomous TPM have been used to reduce the number of defective products from 9.91% to 2.43%, the operating time from 135.17 to 95.45 minutes and increase the OEE from 53.0% to 69.30% (Yalico et al. 2023). Metalworking companies seek to address one of the main problems in the sector which is the poor machine maintenance system. Through lean tools such as 5S, TPM-preventive, and SMED it was possible to increase the MTBF from 4.67 to 5.53 and reduce the MTTR from 1.89 to 1.07 achieving a 12.62% increase in equipment availability with the purpose of maintaining high competitiveness in the market (Espinoza et al. 2022). In addition, after the application of TPM, cycle times have been reduced from 2.69 to 2.27 hours and efficiency has increased from 64% to 72% (Mundaca et al. 2023).

2.2 SMED
Lean tools such as SMED together with TPM tools, in the metal-mechanic sector, have been implemented to reduce the operation times of painting machines from 52 to 25 minutes in a SME of the sector, allowing improvements in the performance of the company by increasing productivity from 1.08 m2/H-M to 1.12 m2/H-M (Florez et al. 2024). Similarly, SMED allowed a metal products manufacturing process to reduce machinery preparation time by 66.2% and increase the productive capacity of the process by 28.91% (Domínguez et al. 2020).

2.3 Productivity
The SMED tool is key to streamline the change processes generating a reduction in production cycle times, which went from 232 seconds to 199 seconds, increasing productivity by 14% allowing profitability to increase by 17.02% in metal-mechanical companies in Peru (Tineo et al. 2023). The combination of Lean tools together with the ADKAR (Awareness, Desire, Knowledge, Ability and Reinforcement) model made it possible to increase the productivity of each operator's effort by 88.51%. This change contributed to an increase of 75.6% in the economic situation of a metal-mechanical company (Quiroz et al. 2023).

3. Methods
An exhaustive search of different research works was carried out during the literature review which presented the same problem of low productivity and availability. In order to solve these problems, successful cases that used lean tools such as TPM, 5S, SMED were evaluated. The following is a comparative matrix where the tools to be used in this research are justified (Table 1).

Table 1. Comparative Matrix.

Causes or objectives **Scientifics Articles**	**High production cycle time**	**Insufficient maintenance of machines**
(Padilla et al. 2022)	SMED	
(Branco et al. 2024)	SMED	
(Gonzales et al. 2024)	SMED	TPM
(Ordóñez et al. 2024)	5S	
(Sánchez et al., 2024)		TPM
(Baldeon et al. 2024)		TPM
(Floríán et al. 2023)	SMED, 5S	
Proposal	**SMED**	**TPM**

3.1 Proposed model

After performing the analysis of the comparative matrix author vs. tools, it was determined that the ideal solution tools are TPM and SMED to face low productivity and availability. The following is a graph of the proposed model that includes each of the components of this research work in Figure 1.

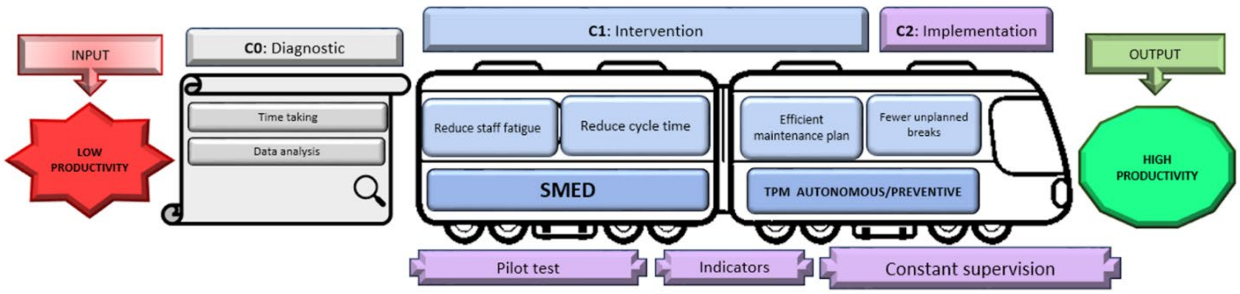

Figure 1. Model Construct

The proposed model consists of two (2) components and diagnostic that will be explained below.

3.1.1 Component 0: Diagnostic

- Time study: The diagnosis begins with the taking of 20 time samples of the different activities of the manufacturing process to identify if there are any wastes that negatively impact the final result of the research.
- Data analysis: To measure the process capability and identify the variability of the process, the CP was calculated to define if the process needs actions. With the help of minitab the times collected in 3.1 were entered and the Cp was 0.77 which, according to statistics, means that the process needs immediate actions.

3.1.2 Component 1: Intervention

This component consists of the application of the SMED tool and autonomous/preventive TPM in 2 subcomponents:

3.1.2.1 Sub Component 1: SMED

This subcomponent consisted of replacing internal activities (activities with the machine off) with external activities (activities with the machine on) in order to improve the manufacturing time from 6.5 to 4 minutes.
Internal activity of threading done by hand was replaced with an automatic activity done with the machine (external activity), this was possible thanks to the change of the int that allowed only one way of operation to a switch which allowed to operate in double direction. In this way the machine performed the threading avoiding the need to rectify and file roughness in the threads.

3.1.2.2 Sub Component 2 : TPM

This subcomponent consisted of the application of TPM in the production process following the following measures:

Training personnel to perform autonomous maintenance to ensure proper preventive maintenance to prevent lathe machine from having to stop..

TPM served as a complementary tool to SMED to ensure that the improvement achieved was maintained over time, this was applied because lathe machine, being in operation longer, suffers greater attrition in cutting/drilling and threading stages, so it was necessary to have a maintenance plan for lubrication and cleaning of blades, drills and threading tools (tap) to manufacture each unit. Likewise, it was necessary to maintain the machinery after each working day of 9 hours a day, cleaning the chuck, towers, carriages and chip tongs and then apply lubricant to facilitate the handling of the machine so that the operator does not over process

3.1.3 Component 2: Implementation

To validate the implementation, a pilot test was carried out for 4 weeks, which was executed by the authors with a frequency of 5 hours per day from Monday to Friday during the day shift. The product chosen for the pilot test was aluminum bolts. Before starting the pilot test, a white run was carried out for one week, with set up times of 1 hour to calibrate the machine before running the work and 3 hours to get used to the operation of the lathe. At the end of the white run, the work was able to progress efficiently.

The application of SMED consisted of replacing activities in the threading sub-process. Initially, it was performed with lathe machine turned off and then it was performed with lathe machine turned on. This was possible thanks to the following measures:

- Change of the ignition key: A three-phase wiring of a two-way key with the motor was made, which allowed to operate the threading subprocess in a single phase without turning off the machine (operate clockwise and counterclockwise).

This measure prevented the following:

- Faulty threads in threading.
- Unwanted measurement of internal and external threads..

The result obtained reduced the number of activities to manufacture an aluminum bolt from 20 to 17 activities which resulted in reducing the cycle time from 6.51 to 4.52 minutes and increasing productivity from 9.21 to 13.28 Units/Minute.

Applying autonomous/preventive maintenance was possible thanks to a previous training program given to the operators by the supervisor. In this program, the tools, frequency and work plans were applied. At the beginning, the maintenance plan was corrective, so it was only performed when the lathe was difficult to handle. The new maintenance plan consisted of performing follow-up maintenance on the manufacturing of each aluminum bolt unit, in the turning, cutting and drilling sub-processes. A weekly operation checklist was used to validate the results of the implementation. To verify the results, overall effectiveness equipment (OEE) was evaluated and increased from 33% to 68%, the mean time to failure (MTBF) increased from 12.5 to 22.43 hours/failure and machine availability increased from 66% to 83%.

Work Productivity (WP): Indicator which measures the productivity of the production process by comparing production times before and after the improvement (Cairo et al. 2023). The objective is to achieve WP of 16.6.

$$WP = \frac{Units\ produced}{Total\ cycle\ time}$$

Cycle time variation (CTV): Indicator which measures the variation in production cycle time before and after the improvement (Cairo et al. 2023). The objective is to reduce the cycle time by 45%.

$$CTV = \frac{Cycle\ time\ before\ improvement - Cycle\ time\ after\ improvement}{Cycle\ time\ before\ improvement} * 100\%$$

Overall equipment effectiveness (OEE): Indicator which measures effectiveness of machines and equipment (Padilla et al. 2022). The objective is to achieve OEE of 70%.

$$OEE = Availability\ x\ Quality\ x\ Performance$$

Availability (A): Indicator which measures the time in which machines are capable of producing in relation to the total time ((Padilla et al. 2022). The objective is to achieve OEE of 75%.

$$A = \frac{Production\ time}{Production\ time +\ Maintenance\ tiem + Downtime} * 100\%$$

4. Data Collection

For data collection, an exhaustive search of bibliographic sources was carried out, for which the first step was to break down the title into components. Subsequently, the SCOPUS search engine was used and the results were filtered by year. Then, the components of the title were searched in SCOPUS, these being the tools to be used (SMED, TPM), the indicators to be improved (productivity, availability) and the sector to which this case study belongs (metal-mechanical).

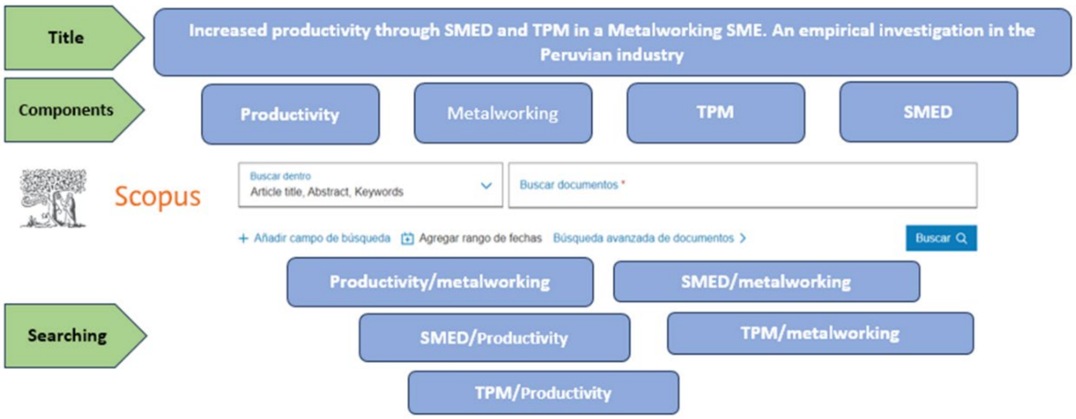

Figure 2. Data Collection

The results obtained were 18 bibliographic sources that were used as references in the literature review, methods and indicators (Figure 2).

5. Results and Discussion

5.1 Numerical Results

Model Results							
Problem	Current	Objective	Improved	Indicator	Current	Objective	Improved
Low productivity	**9.23**	**16.60**	**13.28**	Cycle time und (minute)	6.51	3.61	4.52
				OEE	30.33%	69.29%	68.73%
				MTBF	12.5	15.00	22.43
				Availability	66.14%	75.32%	83.07%

Figure 3. Model Results

Of the above results, the indicators that managed to exceed the proposed figures were MTBF and availability, leaving cycle time and OEE for future improvements. Likewise, an improvement in productivity of 30.5% was observed, not reaching the target productivity (Figure 3).

5.2 Graphical Results

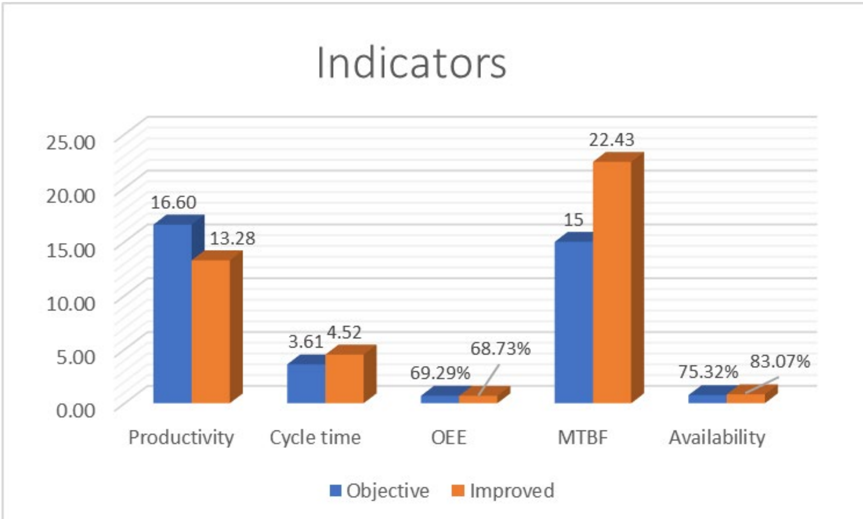

Figure 4. Indicators

It can be seen that all indicators showed improvements, but only 40% of them were able to exceed the target figures (Figure 4) It was not possible to reduce the cycle time to the desired time, nor to increase productivity and OEE to the desired level.

5.3 Proposed Improvements

To implement SMED tool, the first thing that was done was to recognize the stages of the production process, which resulted in 20 activities necessary to manufacture the product and the time required for each activity was assigned. Subsequently, it was classified into internal and external activities performed by the lathe. It was found that 4 activities were internal and the cycle time was 391 seconds (Table 2).

Table 2. SMED Application

N°	Activity	Time(seconds)	Internal	External
5	Threaded with thread (external thread)	42	x	
6	Thread correction	28	x	
7	Filing of imperfections	12		x
15	Threaded with male (internal thread)	35	x	
16	Thread correction	14	x	
Total		**391**	**4**	**16**

As a result of applying SMED and working with the machine turned on and its accuracy, the following changes were obtained:

- External threading made at the same time the correction of the thread and the filing of imperfections, turning 3 activities in 1.
- Internal threading did the thread correction at the same time, turning 2 activities into 1.

The first step was to record the necessary information before and after the implementation of autonomous/preventive maintenance, which was important for the calculation of the machine efficiency indicators (Table 3).

Table 3. Data registered

Registered information	As is	To Be
Number of stops	10	7
Number of times a blade broke	3	0
Total time to solve stops (Minutes)	55	32
Time to calibrate a blade (Minutes)	3	3

The information collected was used to calculate the (OEE) and machine availability for both scenarios (before and after) (Table 4).

Table 4. Main Indicators

Indicator	As Is	To Be
OEE	33.33%	68.73%
Availability	66.67%	83.33%
Performance	53.33%	83.33%
Quality	93.75%	98.97%

Availability was also calculated using the MTTR and MTBF (Table 5).

Table 5. MTTR vs MTBF

Indicator	As Is	To Be
MTTR	6.4	4.57
MTBF	12.5	22.43
Availability	66.14%	83.07%

5.4 Validation

To validate the implementation, Minitab software was used and the T-Student statistical function was applied to verify that there was an increase in the main indicators, which were productivity and availability (Figure 5 and Figure 6).

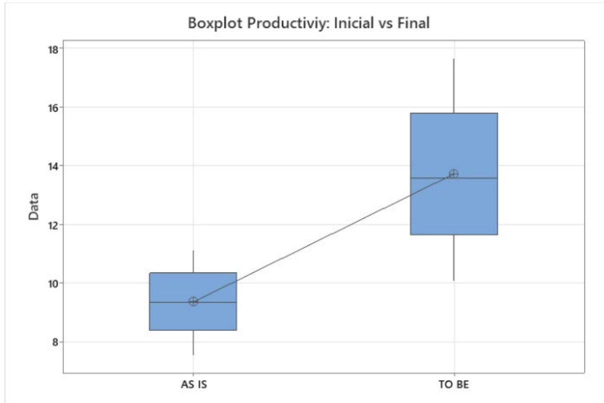

Figure 5. Boxplot Productivity

The comparison between productivity averages before and after the improvement is remarkable, so it was statistically proven that productivity improved.

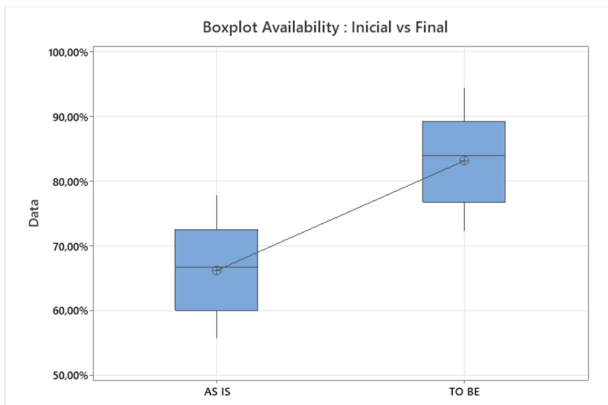

Figure 6. Boxplot Availability

Similarly, the averages of availability were compared where it was found that there was an increase in this indicator.

6. Conclusion

The application of the SMED tool reduced the number of activities from 20 to 17, reducing production time by 30.57% from 6.51 minutes to 4.52 minutes.
The implementation of an autonomous/preventive maintenance plan increased availability from 66.14% to 83.07%. The average daily maintenance time was reduced from 3 hours to 2.5 hours. This result had an OEE impact that went from 30.33% to 68.3%.
Autonomous/preventive maintenance increased MTBF from 12.5 hours/failure to 22.43 hours/failure as the number of shutdowns recorded after the upgrade decreased from 10 to 7.
The use of SMED resulted in increased productivity from 9.23 units/man-hour to 13.28 units/man-hour. Also, autonomous/preventive TPM was applied, which increased the yield from 53.33% to 83.33% and was maintained for 4 weeks.

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