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MAINTENANCE MODEL TO INCREASE THE AVAILABILITY OF CNC MACHINES, THROUGH LEAN AND TPM TOOLS, IN SMEs IN THE METALWORKING SECTOR

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Maintenance Model to Increase the Availability of CNC Machines, through Lean and TPM tools, in SMEs in the Metalworking Sector

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Abstract. The operations in the cutting area are one of the most important activities in the metal-mechanic industry; therefore, the aim is to have the highest availability of the cutting machines. This shows how important this procedure is; in this sense, an improvement model is proposed through the application of lean manufacturing tools in a cutting machine, such as SMED, for the reduction of Set Up times; the application of the 5s methodology, to eliminate waste and increase productivity; TPM, to reduce the number of machine failures, together with a detailed maintenance plan. The model was tested by means of the arena software where the main objective was achieved, which was to increase the availability of the cutting machine by 6.45%, since it was possible to decrease the set up time from 15.71 minutes to 13.25 minutes, as well as to decrease the number of machine failures. This research allows SMEs in the metal-mechanic sector to increase their production and, therefore, generate a greater economic benefit.

Keywords: VSM, TPM, SMED, Method 5s, metalworking industry

1. Introduction

The metal-mechanic industry is very significant as a great driver of countries, since it contributes with technological and industrial developments, the countries that have more developed this industry are Spain, China, Germany, Japan, and the United States [1]. The metal-mechanic industry represents about 16% of the industrial GDP in Latin America, in addition to employing 4.1 million people directly and 19.7 million indirectly [2]. In Peru, between January and October 2018, exports of metal-mechanical products together totaled US$ 486 million FOB, which represents an amount 13.5% higher than the same period last year, whose amount was US$ 428 million [3]. Furthermore, it can be stated that in our country the metal-mechanic sector represented, in 2017, 13.6% of the total value added of the manufacturing sector and 1.7% of the GDP of the Peruvian economy. Therefore, the metal-mechanic activity is one of the industrial sectors that generates a higher added level to the national industry, with effects of 10.2% growth between January and October 2018 [4]. In 2019, the production of the metal products, machinery and equipment sector grew 2.5%; however, between January and July 2020 it fell 33.4%. Consequently, according to the Association of Private Metalworking Companies of Peru (AEPME), the metalworking industry has been operating at 50% [5].

The identified problem, according to the literature guides us to different case studies where it alludes to various factors, such as the search for process planning and a cutting parameter scheme, to minimize energy consumption, measuring processing times (cutting time) and non-processing times (setup time and tool changes) [6]. In another research it could be identified that there are geometric errors with the use of the CNC machine, given the calculation errors that exist in the programming, which brings consequently the failure to measure the axes, which results in the accuracy for cutting is not adequate [7]. In addition, that as a result gives the reprocessing of the materials to be cut. On the other hand, in research, there was a problem about the use of CNC machines, which are the high set up times, where the operator intervenes, and it was found the great distance between the cutting machine and the PC table, the fatigue in the process of setting the machine and the search for data information on the computer, which as a result formed long times in the Set Up [8]. The above-mentioned evidence that the metal-mechanical companies that have within their

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processes the use of CNC machines, have various problems, so it is important to continue researching for new industrial solutions.

Under this context, it is necessary that the SMEs that use CNC machines, are more efficient to have a greater availability of the use of this. For this, a case study was chosen to reflect the problem of the use of the cutting tool, due to its various interventions, along with unscheduled downtime, due to the high set up times, the failures of the CNC machine itself and the breakage of inventory, which generates a loss of 8.03% during the production process of the case study. In relation to this problem, an improvement model was developed combining VSM, 5S, SMED and TPM tools, all under the Lean manufacturing method. This model was developed based on the success cases that presented similar problems to the study. This research not only helps to solve the problems presented but also contributes to the scientific community. This research offers a combined model of various Lean manufacturing tools applied to the use of a CNC machine. It should be noted that there are several investigations where the various methodologies are used in SMEs, separately; however, there is no article that combines all these tools, mentioned above, in the sector.

2. State of the Art

2.1. Maintenance Models to Increase Machine Availability in the Metal-mechanical Sector

Currently, there is a high rate of growth in the industrial market, especially in the metal-mechanical and manufacturing sector, generating that machinery and equipment become more intelligent and accurate devices showing that maintenance schedules require evaluations and extraction of the environmental factor in a more constant way [9]. Given this situation, it is essential for operators and engineers to continuously seek innovative strategies to improve maintenance schedules; since poorly maintained equipment and machines can generate random breakdowns, these mostly occur in many fields, such as production, industry, and manufacturing. Therefore, the implementation of a maintenance model is required to improve the availability of industrial machines and equipment that serve as pillars to maintain the competitiveness and profitability of the company belonging in all sectors of industry [10], [11]. Also, the maintenance model has to present the concept of system availability that minimizes the use of technology, maximizing its management to companies with lower turnover [12].

In the case that a maintenance model is not raised or an inadequate one is established, it will not be possible to address challenges or future goals with respect to reliability and maintainability of subsystems that are directly related to the availability of equipment, in addition traditional methods cannot be counted on, since they present limitations and little optimal precision due to their little interest in the risk rate of the equipment [13] [14]. However, if an adequate maintenance model is proposed, including its follow-up, it is possible to intervene criteria obtained through a cost-benefit analysis; for example, reduction of downtime, improvement of OEE, reduction of maintenance and operational costs [10].

2.2. Lean Manufacturing in the Metalworking Industry (5s, SMED)

In the metalworking industry, companies seek to apply lean manufacturing tools, with the objective of improving product quality, reducing processing times and reducing costs. For this, there are two of the most important tools, which are the SMED and the 5s, where they focus on seeking continuous improvement in production; since, it plays an important role in the manufacture of machinery within this sector; measuring quantitatively, the concepts of reducing times in the configurations and focusing on reducing waste in the process; giving emphasis to eliminate problems in production and impacting the quality of the product [15]. In the first tool, it seeks to turn activities somehow from internal to external configurations, giving time to operators to do other activities; while, in the second, it serves to track and keep updated the processes, along with the identification and classification of waste, the correct maintenance of the clean workplace and instructing the correct use of work tools, for a correct production [16]. These 2 tools help to identify where the improvements are in the production processes and helps in decreasing the overall time [8].

To reach the correct implementation, a value stream mapping has to be done, to identify the activities that add and do not add value, addressing the most basic 5s techniques and reorganizing the activities of the workplaces; implementing the SMED, in the machines and the 5s, for the elimination of waste [18]. It is known that in metal-mechanical companies, which managed to implement these tools, achieved efficient indicators, along with the reduction of waste in the manufacturing process, such as operator downtime, resource consumption, and were also able to reduce environmental impacts by greenhouse gas emisións [19], [17].

2.3. TPM in the Metal-mechanical Industry (Autonomous Maintenance and Planned Maintenance)

The implementation of TPM (Total Productive Maintenance) in the metal-mechanical industry has the purpose of maximizing the effectiveness of the equipment by optimizing the availability, performance, efficiency, and quality of the manufactured products. Promoting better maintenance of machines through autonomous maintenance and preventive maintenance, establishing appropriate strategies for the life cycle of equipment, and involving staff members from top management to shop floor workers [20]. Autonomous maintenance aims to keep equipment activities uninterrupted by preparing operators to perform some equipment care in different periods, such as daily, weekly and monthly, according to the identified needs of the machine. On the other hand, in preventive maintenance, it requires the expertise of technicians specialized in maintenance; which is fundamental for its realization, since it seeks the conservation of the equipment in its life cycle, giving maintenance periodically, under the terms of the manuals of the machines [21].

The autonomous maintenance, is given thanks to the education and training given to the operators, where they are usually in charge of cleaning, lubrication, tightening, adjustment and inspection of the equipment; along with this, they are asked to participate in some improvement in their activity and communication about the production of the machine, this to protect the machine, ensuring its long life and good quality of the manufactured products [22], [23]. With respect to preventive maintenance a check sheet is established with the aim of improving the MTBF (mean time between failures) and MTTR (mean time to repair), with the purpose of an improvement in the OEE; this planning system must be efficient and effective during the life cycle of the equipment [20] [24].

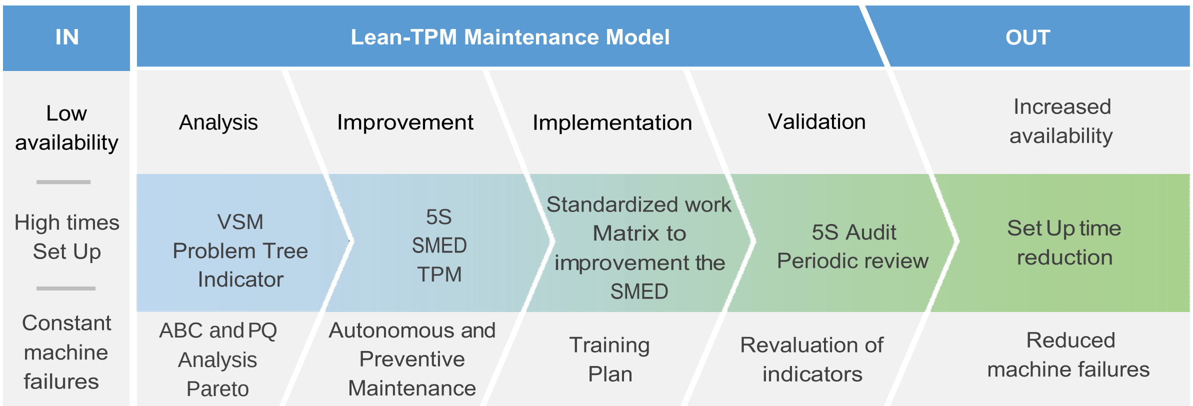

Fig. 1: Proposed model

3. Contribution

3.1. Model Basis

For the development of our maintenance model to improve the availability of CNC machines within an SME in the metalworking sector, we took as references several articles related to the Lean Manufacturing philosophy, more specifically, articles focused on the Single Minute Exchange of Die (SMED) and 5s tools, in addition to the use of Lean techniques, we also considered the TPM methodology, due to its direct relationship with the maintenance of equipment and the availability of this, for this case we searched for articles on autonomous maintenance and planned maintenance. Likewise, researches that employ these two methodologies in a single study were taken into account, in order to present an innovative contribution to this field. Unlike other maintenance models, the model developed in this research will not take into account the amount of wasted materials as an indicator of improvement nor the use of technological tools as part of a maintenance monitoring system, this research is focused on the machine operator relationship in the work area incorporating a methodology on maintenance to reduce the number of failures by the machinery and the misuse of the operator responsible for it, with the implementation of a system of care and order for all elements belonging to the area. Also, a new plan to reduce the modification time of the machine in its operation. Next, a comparison matrix between the proposed model causes and state of the art is shown.

TABLE I. COMPARISON MATRIX OF THE CAUSES OF THIS RESEARCH VS. THE STATE OF THE ART

Causes / **Articles**	***Machine Control Inefficiency***	***Machine Failure***	***Set Up time management***	***Wastes deposited in the stations***
Belhadi, A., et al.			SMED	5S
Nallusamy, S., et al.	TPM	TPM		
Pinto, G.; et al.	TPM	TPM		
Oliveira, J.; et al.		VSM, LEAN	VSM	VSM
Ribeiroa, IM.; et al.	TPM, 5S	TPM, 5S		TPM, 5S
Bevilacqua, M.; et al.			LEAN, TPM	LEAN, TPM
Proporsal	**Planned Maintenance**	**TPM**	**SMED**	**5S**

3.2. Model Components

The components of this proposal consist of the application of the tools mentioned in the state of the art; that is, a maintenance model integrated by the Lean Manufacturing tools and the Total Productive Maintenance TPM methodology is proposed as a solution to the problem of low availability. These methodologies are implemented due to its extensive proposal of improvements that are adequately adapted to the difficulties located in the company that are determined by the problem tree, also these proposals stand out in the use of the following tools: SMED, for the reduction of modification activities in the use of the machine that generate high Set Up times; 5S, materials located inadequately in the workstation and little order in the dynamics of the workstation. The following is a brief explanation of the components that are part of the proposed model.

A. Problem Analysis

Before implementing an improvement proposal, a set of statistical and administrative tools must be applied to determine the current situation of the company. To detect the problems presented by the production line in the case study, an ABC and P-Q analysis is used beforehand to determine which production line will have the greatest positive impact when applying the improvement proposal. Then, a VSM is used to perform a more detailed analysis of each production stage to find the station that requires a continuous improvement approach using machine availability, operator efficiency, and product quality in real-time as indicators to support the problem. Then a problem tree is made to find the causes and sub-causes that are part of the problem and apply the necessary tools to solve the problem. Finally, the causes with the most significant impact on the problem presented by the production station will be identified through the paretos.

B. Improvement proposal

It will focus on developing the tools that will be implemented in the continuous improvement to solve the difficulties presented by the company. First of all, a proposal for the implementation of the 5S will be executed; it will start with SEIRI (Select), where the path that the steel plate will go through is presented, in order to be classified to be cut, stored properly or put together with the wastage of plates and be sold by the company; then stopped by SEITON (Order), where the operator goes to count the plates that he has in his area, previously classified and ordered, to begin with his cutting activity; then by SEISO (Clean), in which, cleaning measures are proposed to minimize the obstruction in the space of the cutting area. It will take the creation of a cleaning kit for the plates and equipment; to reach SEIKETSU (Standardize), creating a table of scores to keep track of the operator already adopted the actions that will achieve the 5s; and finally, SETSUKE (Discipline), which will try to maintain the changes established in the actions of the organization, turning these changes into a habit and thus endure over time. Secondly, the 4 conceptual phases for SMED will be defined with the purpose of identifying which operations are related to the activities that occur within the cutting station in order to establish a reorganization of the activities with their respective improvement with the purpose of reducing Set Up times.

Likewise, for its correct definition, a time study has to be carried out with respect to all the elements related to the cutting station, both the machines and the operator. Finally, it is necessary to develop a maintenance plan with respect to the failures that the CNC plasma cutting machine presents, so it is necessary to develop a modal analysis of failures and effects taking into account the severity, occurrence and detention of these, as part of the development of the AMEF, a direct interview was conducted with those directly responsible for the area, in this case, the operator and the head of design to have greater validity. Already with the detected problems, a continuous analysis of the problems that can be corrected through corrective and preventive actions is performed. In other words, as a solution to these defects, two pillars of Total Productive Maintenance (TPM) will be implemented, autonomous maintenance and planned maintenance with the objective of reducing unplanned machine stoppages.

C. Implementation

In this section, it is sought to implement the improvement proposals according to the needs of the company. In the first place, internal training and constant monitoring of activities will be carried out by a supervisor, who will be in charge of ensuring that the operator complies with the measures imposed as part of their work on a daily basis, so that they remain in place in time, and the operator must receive a series of follow-ups to apply the 5s tool. Second, an improvement matrix of the SMED configuration process will be made for the CNC cutting machine to identify the operations that have the ability to be modified from internal to external for the better understanding of the operator. Finally, as the last improvement process, a training plan is planned to improve operation and maintenance capabilities, the pillars of autonomous and planned maintenance will be used. In the case of autonomous maintenance, it focuses on 4 ideals to follow which are safety, cleaning, elimination of contaminants, optimal conditions for the machine and improving the capacity of the operators in their operating skills; therefore, with the help of the 5s audit, the operator will have the ability to monitor and inspect the voltage and air level of the CNC machine, in addition to the regular levels of sensors present. In the case of planned maintenance, it is to avoid that the machine has failures, unnecessary stops due to lack of scheduled maintenance or identification of improvement points.

D. Model Validation

As the last component of the proposed model, it consists of the validity that presents the results of the implementations of the continuous improvements mentioned above to verify that the objectives established in this work meet the expectations raised through the indicators related to a comparison of the current situation with the proposed improvement. Likewise, to ensure that the implemented measures are correctly implemented, audits will be applied in a determined period to validate their constancy and good performance.

3.3. Model Indicators

To evaluate the improvements that will be achieved, the indicators obtained will be compared with those previously mentioned since an improvement is sought with the implementation of the proposals.

A. Availability index: It establishes the time that the machine is working concerning the total time planned for its use, which will increase the availability from 71.63% to 80% to add 8.93% to the availability of the machine.

$$\%\ Availability = \frac{Production\ Time}{Time\ scheduled\ to\ produce} \times 100$$

B. MTBF: Calculate the number of failures; and give the time that elapses between one failure and the next; therefore, it will increase the time from 1.25 hours to 2.5 hours, improving 100%.

$$MTBF = \frac{Total\ machine\ time\ available\ for\ production}{Total\ number\ of\ stoppages}$$

C. MTTR: This indicator is used to calculate the average time in which the machine is repaired after a failure has occurred; therefore, the time will decrease from 9.38 minutes to 5 minutes, an improvement of 46.7%.

$$MTTR = \frac{Total\ machine\ repair\ time}{Total\ number\ of\ faults}$$

D. SET UP: This indicator sets the time the operator takes to set up the machine; therefore, the time will be decreased from 142.94 minutes to 120 minutes, a 16.05% decrease.

$$Setup\ time = Total\ of\ the\ machine\ in\ use - Production\ time$$

4. Validation

4.1. Validation Scenario

Through this academic research, the Arena Simulation tool was implemented as a validation method. Therefore, it was necessary to develop a diagnosis regarding the production cycle, in order to determine the real problem presented by the plant and its points to improve. Also, a model of the simulation design is presented, demonstrating the key processes of improvement of the production line, specifying the inputs and outputs of each one.

4.2. Initial Diagnosis

Currently, the main problem of the SME company in the metal-mechanic sector is low availability, due to the occurrence of events that do not generate added value to production, such as downtime, machine failures or reprocessing time. In this research, these problems have a current economic impact amounting to S/. 6,995.65, which represents 8.03% of the total operating cost and 16.79% of the gross profit during the 6 months studied. As applied in the VSM, it is demonstrated high times of unscheduled stops that occupy 88.75% of the non-productive hours of the production process, causing that the availability of the machines within the company presents a percentage of 71.61%, differing with respect to the world standard with 18.39 points; to find its main causes, the Pareto diagram was used and resulted that 81.56% of the machine downtime are: High Set Up Time, Machine Failure and Inventory Breakdown. The indicators that need to be improved in order to solve these problems and increase availability are shown in the following table.

TABLE II. INDICATORS RESULT

Indicators	Present	Objective	Variation(%)
Availability rate	71.63%	80%	8.93%
MTTR	9.38 min	5 min	46.7%
MTBF	75 min	150 min	100%
Set Up	142.94 min	120 min	16.05%

4.3. Validation Desing

For the development of the simulation, certain variables were considered in which the scope of the system, the number of runs in the system that ensures the reliability of the system, along with the entities with the restrictions and the time applicable to the simulator were considered.

A. Scope of the system: For the development of the simulation, the scope of this must be taken into account, so a map is developed from the cutting area to the assembly area; where the tools of continuous improvement, mentioned above, are applied, omitting the reception of materials and dispatch of equipment, finished product, since, as mentioned above, the type of production is "Make to Order"; therefore, the timing of these two activities is negligible. For the production of a machine, 9 plates of 1.4x2.8 m2 are required, therefore the simulation begins with the classification of the plates that enter the cutting machine, working with 4 types of plates with different thickness and material, because the time of modification, set up, varies depending on the type of steel and thickness of the plate, however the cutting time is similar for all cases. The welding station and painting are interpreted as simpler processes, because they are processed as a single entity. Unlike the lathe station, which enter 5 plates of the same type and thickness, therefore they will join with the entity that leaves the painting station to form a unified process of a single entity for the assembly station.

B. Input data processing: A time measurement was carried out at each work station to determine the time required to complete their functions and the production of each piece. In order to determine the total time of the production cycle and the Set Up times of the cutting area.

TABLE III. ENTITY DISTRIBUTION TIME

Random Variable	Input Analyzer
Cutting	UNIF(74, 78)
Soldier	UNIF(1.87e+03, 1.97e+03)
Painting	UNIF(340, 380)
Turning	UNIF(80, 95)
Assembly	UNIF(80, 95)

C. Current situation with proposal for improvement: To obtain the number of simulation replicates, the following factors were considered: number of initial replicates, 30; margin of error, 0.09 and desired margin of error, 0.045. Obtaining a total of 120 optimal replications.

TABLE IV. RESULTS OF THE CURRENT SITUATION VS. IMPROVED SITUATION

Variables	Now	Improvement
Average total set up time (min)	15.71	13.25
Time MTBF (min)	79.54	153.98
Time MTTR (min)	9.58	5.5
Total failures	10	6
Cycle time (min)	4497.76	4463.86
Availability	71.63%	78.08%

To obtain an improvement in the cutting area, two pillars of total productive maintenance had to be implemented: autonomous maintenance and preventive maintenance; in order to reduce unplanned machine stoppages that occur in the production process and the time required by the operator to solve these problems.

Another opportunity for improvement that was applied was the reduction of modification times (Set Up) of the CNC cutting machine, since it presented a degree of uncertainty with respect to time, also that these improvements can be implemented optimally, the 5s tool was applied. Next, new Set Up time distribution values will be presented.

An improvement of 16% was obtained, on average, with respect to the Set Up times, since the use of CNC machines has fewer unplanned failures at the time of operation, this reduction in the number of failures is 40%. Finally, the proposed maintenance model will increase by 6.45% with respect to the availability of the CNC machine.

It was possible to validate our simulation after the courtship with other investigations, where the mentioned tools were implemented in a real scenario; in the first place, the implementation of the 5s method, with its guidelines to follow until the established changes were maintained, establishing audits with evaluations of determined scores, from 1 to 4, achieving an improvement of 29 to 40 points, range that would be perfectly located in the general evaluation criteria [24]; Secondly, the implementation of the SMED tool, in a CNC machine; where, it was possible to reduce the set up times by 12%, having 11 activities; a considerable percentage counting the number of activities, where the percentage of conversion from an internal to external activity comes out, therefore, it is a coherent result [8]; however, the cycle time does not change so drastically. Finally, the application of TPM, total productive maintenance, applied in a CNC machine, in our research, mainly presents improvements in the MTBF, increasing almost double with 94% and on the part of the MTTR, there is a decrease of 43%; giving optimal values, extremely important [22], since it is a result that strengthens the application of TPM, giving as a conclusion an increase in the availability of the CNC machine of 6%, therefore, an increase in its OEE.

5. Conclusions

The purpose of this research allows us to have a better context of the SMEs of the metal-mechanic sector in Peru. The results determined an improvement in the KIPs proposed during the validation of the study. For this reason, the following conclusions are presented.

- Under the simulation it was possible to see an improvement of 33.9 minutes in the overall production cycle, demonstrating in a positive way that the lean manufacturing tools and the measures of the improvement model work.
- Through the analysis of causes, performed by the Value Stream Map (VSM), it was shown that the basis of the entire process was the cutting area, therefore, the most important; in addition to the Pareto diagram, which indicated that it had periods exceeding the expected, so it came to give high times of unscheduled stops that occupied 88.75% of the non-productive hours in the process.
- It was shown that thanks to the lean manufacturing tools applied, such as SMED, TPM and 5s, it was possible to increase the availability of a cutting machine by 6.45%, thus improving its production capacity.
- In order to reduce from 10 to 6 machine failures, the MTTR and MTBF were mainly modified, where the former decreased by 3.38 minutes and the latter increased by 78.98 minutes.
- For the verification of compliance with all the established parameters of the 5s method, a supervisor is designated, who will keep a record of the performance of the same, indicating the established scores, where the highest is between 35 to 40 points

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