Maintenance management model to increase availably in a metalworking SME applying TPM, SMED and PDCA

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Abstract*– The variability of demand has led metalworking SMEs to develop more efficient processes. Therefore, increasing availability is a necessity to maintain competitiveness in the market. The main problem of the sector is the deficient maintenance system that involves machine and operator performance, causing losses in 8% of profit. Therefore, a maintenance management model is implemented, where the basis consists of improving the work environment and operator performance through 5S and TPM (Safety, Health and Environment). Subsequently, the disuse and setup time of each machine is reduced through the application of SMED, autonomous and preventive maintenance. The level of availability was increased by 4% and continuous improvement was applied to the indicators, which further increased availability by 2%. In summary, the successful implementation of the model depends not only on the diagnosis of the machines, but also on the commitment of the operator and management.

***Keywords*-- metalworking, autonomous maintenance, preventive maintenance, SMED, availability**

I. INTRODUCTION

The metalworking sector is highly competitive because it constitutes a fundamental link within the industry by producing durable consumer goods that are essential for daily life [1]. Likewise, 75% of the companies in this sector import 42% of their machinery and among their most used raw materials are steel, welding and galvanized wire [2]. On the other hand, this sector has a high participation in the generation of jobs with 20% of the total jobs generated in each country, with Mexico having the highest participation in Latin America [3]. In Peru, it generates about 355 thousand jobs, in addition, it is a growing sector, since in 2017 it had 4.9% of manufacturing activity and in 2018 it grew to 6.1% [4].

One of the main problems faced by this sector is the low availability of equipment because it means higher production costs, since more man-hours are needed [3,4]. This is caused by a low performance of the machine due to the reduction of its speed, breakages, requested stops, lack of qualified personnel, which culminates in loss of time. Given this, it is advisable to apply TPM, since its objective is to achieve availability close to 100% by eliminating unplanned stops of equipment and waste. In a case study of the metalworking sector, the level of compatibility of the 5S technique with the TPM achieved an increase in availability up to 97% [5]. While in another, it increases the level of availability by 8% [6]. In addition to this, by implementing the PDCA application, the result of improving availability can be increased by up to 4% [7]. Likewise, the SMED reduces production time and machine adjustment times through standardization in a range of 45% to 62%, so that availability increases [8].

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This research aims to evaluate the level of impact of applying the TPM, SMED and PDCA methodologies in an SME in the metalworking sector. The stated objective is to increase availability, by reducing downtime and machine configurations and improving the environment and operator safety. On the other hand, making the improvements implemented continue to last and improve during the development of the project is the second approach. For this, it is necessary to integrate all areas towards the same objective and the use of 5S, since it has a great impact on the organization [5, 6, 3]. In addition to this, the SMED methodology will help reduce lead times. preparation, changes and adjustments [7, 8, 9]. Finally, a maintenance management model supporting the aforementioned methodologies is shown.

The structure of the article consists of a research section on the metalworking sector. Next, the techniques and methodologies are developed. Subsequently, the diagnosis of the study company was carried out, in which the causes of the low availability problem were identified. Then, the methodology to be applied is established, it will start with the 5S technique, whose beginning is vital for the subsequent application of methodologies. Then, the TPM and SMED methodologies are applied to increase the availability percentage. Then, the PDCA method was added to obtain a long-term result. Finally, a simulation was performed, the results were analyzed and a conclusion was obtained.

II. HINTS STATE OF THE ART

A. SMEs in the metalworking sector and their level of availability

The variability in demand has led metalworking companies to develop more efficient processes [13]. For this reason, increasing the level of availability is a necessity to maintain competitiveness in the market [14]. This sector presents low availability due to the poor maintenance system and interruptions induced by the operator [15,16]. The evaluation of the availability in SMEs is even more critical, due to the fact that a level between 70% and 80% is registered; while medium and large companies register between 80% and

92% [17,18]. The main difference between the availability levels lies in the economic support and standardized processes. For this reason, SMEs need lighter and more efficient methods that allow them to increase their availability, mentioning the TPM as the main solution [19].

On the other hand, the availability to achieve in SMEs in the metalworking sector is over 90%, because obtaining a percentage higher than 95% requires a greater investment, which SMEs do not usually consider [5,3]. . Finally, the TPM methodology is the specialized technique for increasing availability in metalworking SMEs because it increases the efficiency of the machinery, the personnel and the budget if the solution is accessible [19, 14, 17].

B. TPM, 5S and SMED focused on the operator

The TPM seeks the moral increase, job satisfaction and safety of workers. This is developed in the safety, maintenance and environment pillar [7]. Companies must analyze the risks, the space and evaluate the level of operator satisfaction. For an operator to obtain a commitment to the company, he must feel important [20]. On the other hand, the 5S tool is the basis of all maintenance models [9, 21]. The 5S method not only improves communication between employees, but also helps them acquire skills such as discipline to reduce downtime, delivery time, inventory, defects, injuries and associated costs [10.22]. A part of the SMED methodology focuses on developing the skills and abilities that the operator must acquire to reduce adjustment times through the improvement of their activities [23, 24].

Finally, the successful implementation of TPM and SMED depends not only on the diagnosis of the machinery, but also on the skills and abilities that the operator must obtain as it is considered the main component. Applied SMED, TPM and 5S in the operator, a reduction of the flow of movement in the plant is obtained close to 70% and an increase of 50% in production. Finally, the availability increases between 10 to 15% [25, 26].

C. *TPM and SMED focused on maximizing machine availability*

The TPM presents a focus on equipment maintenance in order to achieve almost perfect production processes and in optimal times [27,28]. The TPM seeks 100% availability of production equipment by eliminating machine stoppages caused by degraded machine performance [6]. In this sense, it can bring benefits to the industrial unit to obtain greater control of equipment, reduce times and failures. Thus, coordination between production and maintenance can be achieved [29]. Autonomous maintenance is a pillar whose objective is to eliminate all forms of time wasting. It is linked to stoppages in the production system due to machine breakdowns, which invariably produce a direct impact on the performance of the process [30]. On the other hand, planned maintenance allows preventing machine downtime and maximizing availability [31]. The purpose is to extend the life cycle of the equipment and keep it in satisfactory working conditions through an inventory control of spare parts [32].

The SMED method is the best solution when it is required to reduce preparation times, changes and adjustments [8]. The tool is based on reorganizing the activities (external and internal) of a given process and performing some of them in parallel so that they require as little time as possible in general [12]. Configuration times are reduced by an average of 50%, after converting some internal activities to external activities, deleting activities and combinations of activities to be performed in parallel [11].

Both methodologies can complement each other and increase availability above 10%, in which the SMED focuses on configuration times and the projected TPM on the prevention and control of equipment maintenance [33,34].

D. The PDCA cycle in a maintenance model

The Deming cycle is a strategy that allows to maintain and improve a proposed solution [35, 36]. It is developed in four procedures: plan, do, verify and act. This tool is used in various TPM proposals in order to maximize results and develop a continuous improvement cycle [37,38]. On the other hand, the Deming cycle is not only a technique that allows product quality control, but also the development of processes and logical programs for continuous improvement in different types of industries and machines [39,40]. . The application time varies depending on the size of the company and the level of standardized processes. However, the results can be seen beyond 6 months and in SMEs even up to 1 year [41,42]. Added to this, the PDCA allows to increase the availability level of the machines to a higher level than when only TPM and 5S are applied, so that when it is reinforced with this technique, the availability can increase 4% more than what was previously achieved [35.37].

In short, it is advisable to include the Deming cycle in the new maintenance models. Thus, a new organizational culture will be achieved both in the operators and in the administrative area, which must be measured through indicators that verify the correct implementation of the PDCA [42,43].

III. CONTRIBUTION

A. Basis

The TPM implementation model in SMEs and the TPM implementation model based on continuous improvement are being considered as a basis, since they focus on increasing the level of availability in SMEs in the metalworking sector by reducing adjustment times in the machines and improve understanding of operator performance. In addition, they want to support their proposals based on continuous improvement so that as the project progresses, the indicators are improved with monitoring and scheduled measurements.

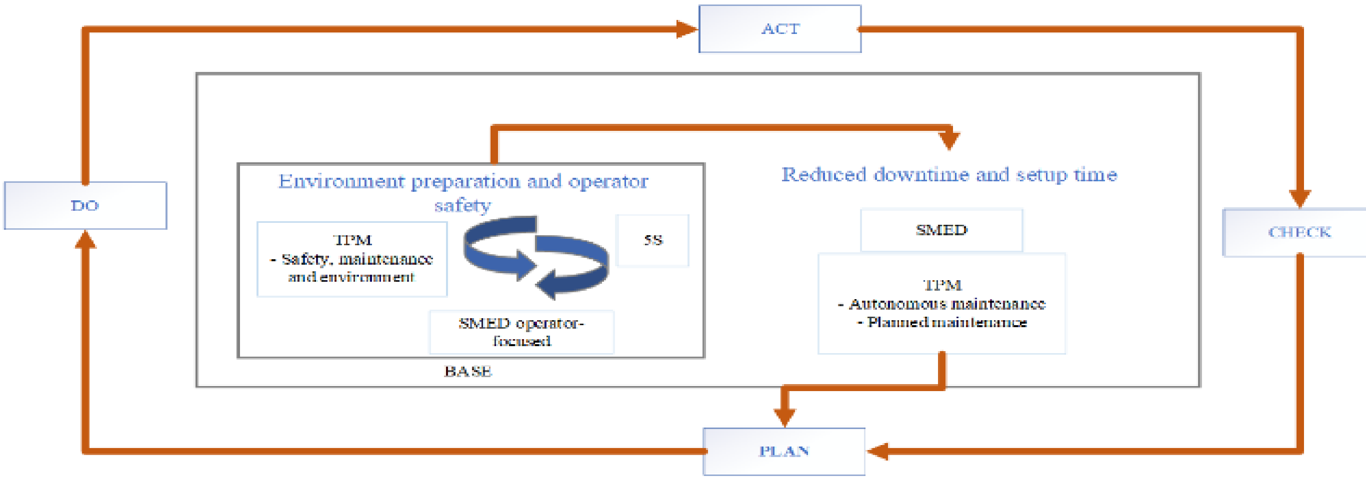


Fig. 1. Maintenance management model

The proposed model of Fig. 1 is distinguished by integrating an approach prior to technical development, which is based on the operator and the workspace. This addition is essential when talking about an SME because they present disorganization. On the other hand, another distinction is the development of the continuous improvement cycle that evaluates the indicators and thus the SME does not return to problems before implementation.

B. Proposed Model

- Component 1: Environment preparation and operator safety

This component is intended to create an orderly environment that provides the operator with spaces that are correctly delimited according to their use. Also, it is intended to provide you with a clean and safe environment based on new rules and tools. Given that, as there is no method to organize their work, it is now easy for pieces to get mixed up or get lost in the workshop. In addition, as there are scraps and waste in the aisles, they put the integrity of the operator at risk, since they can trip. Therefore, to achieve this, 5S will be applied, which helps to order and reduce site waste, TPM (safety, maintenance and environment) and SMED focused on the employee in order to provide security when performing their work and improve their skills.

- Component 2: Reduction of downtime and configurations

This component focuses on increasing machine uptime and simplifying or eliminating pre-use setup. For this reason, machine maintenance management techniques are being applied, among them are the pillars of the TPM, among which autonomous and planned maintenance is being selected in order to give the pertinent care to the machines at the appropriate time according to the manual they have, since that way you can ensure their useful life, the quality of their work and reduce the time of unnecessary stops. Next, SMED focused on the machines will be applied, since it is desired to reduce the time of part adjustments and waiting times.

- Component 3: Sustain based on continuous improvement:

This component has the purpose of keeping the maintenance management system in constant monitoring, innovation and improvement through the application of the Deming cycle, since in this way the progress achieved is avoided. Given that, as the scenario is an SME that has never experienced compliance with a maintenance system, following the steps correctly and with discipline is a complicated task, so constant monitoring by a designated auditor will allow errors to be identified when applying predictive, corrective and autonomous maintenance, which will later be discussed in a meeting.

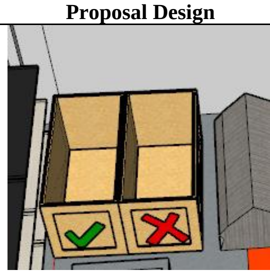
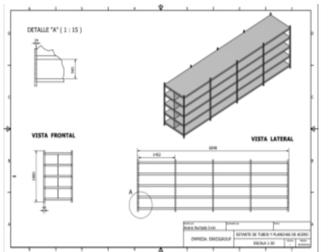
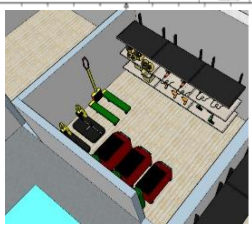
C. Model Detail

- Component 1: Environment preparation and operator safety

To improve the environment of the operator, the following actions observed in Table 1 have been carried out.

To evaluate the risks that the operator faces in his work, an analysis has been carried out using the IPERC matrix, which aims to train operators in risk prevention of workshop machines, train on the importance of the use of PPE and then proceed to buy the complete clothing that a welder requires. Since, when handling the machines, they can suffer burns and cuts that make them unable to work. Also, the purchase of earmuffs is proposed to prevent the deterioration of their hearing level.

TABLE 1
IMPROVED OPERATOR ENVIRONMENT

Description	Proposal Design
It is proposed to make two wooden boxes. In the first one are the rusty metal parts that can still be recovered through a sandblasting process. In the other, the metallic pieces will be located whose excessive deterioration prevents a profitable repair.	
To organize the steel tubes, it is proposed to implement a shelf that allows the tubes to be separated by their diameter and their shape, whether circular or square. Also, the plates and angles must be accommodated in it by their thickness, width and length	
For the order of the machinery, a warehouse model has been designed with the expected organization of each piece of equipment. In addition, the consumables of each machinery have been considered in the corner of the shelf.	

Finally, a study of the capabilities of each operator was carried out. based on the compendium of competencies to obtain the welder's certificate, which is detailed in Table 2 and Table 3. Therefore, each competence and knowledge was evaluated taking a rubric as a reference to assess whether the staff meets the required standards. Based on this, it was identified that there is a poor knowledge of the care of the machines. For which a training entitled: "How take care of and increase the useful life of the workshop machines?".

TABLE 2
CAPABILITIES REQUIRED BY A WELDER

N°	Qualification Required	Required capabilities of the position
1	5	Ability to work with great accuracy.
2	5	Physical prowess (strength and agility)
3	5	Ability to follow blueprint and technical drawing instructions
4	5	Ability to follow health and safety regulations
5	5	Capacity for teamwork

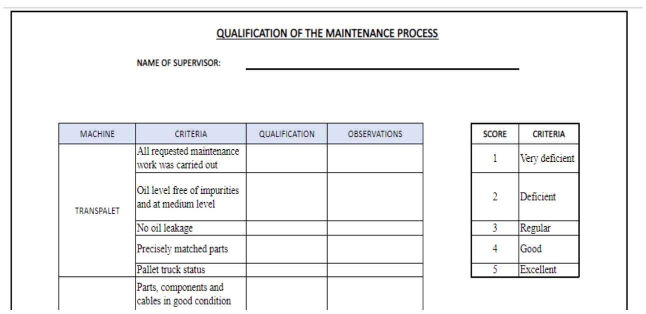
TABLE 3
SKILLS REQUIRED BY A WELDER

N°	Qualification Required	Required knowledge of the position
1	5	Technical knowledge of the different materials that can be used.
2	4	Knowledge of electrical work
3	5	Knowledge of working at height safety
4	5	Knowledge about safety and prevention when using machines.
5	5	Knowledge of handling machines
6	4	Knowledge of care and maintenance of workshop machines

After that, an evaluation format of the results was carried out in order to verify that the operators have managed to internalize the teachings. Since, in previous trainings, it was not verified and there were nonconformities that affected expectations.

- Component 2: Reduction of downtime and configurations

In the first place, autonomous maintenance will be applied, for which maintenance has been scheduled for each machine based on its manual, which describes the activities to be carried out and the schedule. This new measure will be informed at a scheduled meeting, which will be given by the person in charge of the workshop. It should be noted that these activities will be carried out by the person in charge of using the machine. Also, a monthly or semi-annual record of maintenance will be kept so that there are no oversights or disorder. In addition, the supervisor will be in charge of verifying that everyone complies with what is assigned and will qualify the performance of each one as shown in Fig. 2.


QUALIFICATION OF THE MAINTENANCE PROCESS

NAME OF SUPERVISOR: ____________________

MACHINE	CRITERIA	QUALIFICATION	OBSERVATIONS
TRANSPALET	All requested maintenance work was carried out		
	Oil level free of impurities and at medium level		
	No oil leakage		
	Precisely matched parts		
	Pallet truck status		
	Parts, components and cables in good condition		

SCORE	CRITERIA
1	Very deficient
2	Deficient
3	Regular
4	Good
5	Excellent

Fig. 2. operator performance evaluation

Secondly, a visit schedule was drawn up for specialized technicians in each machinery in order to assess the current state of the equipment. It is worth mentioning that the main function will be to evaluate the internal part of the equipment, the engine as the main objective.

On the other hand, a macro programming of the Excel program will be carried out, to monitor the inventory of spare parts, consumables, etc. And later the purchase order can be programmed according to the minimum stock alert. In this way, when the change of part to the machine is required, they will be carried out without waiting.

Finally, to carry out the SMED application, the door manufacturing process was evaluated using a DAP, since according to the time study record it is the process that lasts the longest. According to what was found, there are extensions without a fixed place, so they are easily lost or entangled. All this leads to wasted time before the use of the machines. Based on this, it is proposed to make the connections of the currents permanently on the work table, since ground connections must be used, so that it makes it easier for the operator to connect their machines quickly and with greater safety.

- Component 3: Sustaining

Every two months the progress achieved will be evaluated. For this reason, as shown in Fig. 3, the time lost in each machine and its respective description will be taken. Then the failures in the machines will be counted, what each one of them consists of and how long it takes to repair them. Subsequently, with the data collected, the company's MTBF, MTTR, availability and OEE will be evaluated. According to what is obtained, action measures will be taken in a meeting with management.

TIME RECORDING FOR THE "MACHINE".

NAME OF PERSON IN CHARGE: ______
START DATE: ______ END DATE ______

Nª	Time lost	Description:
1		
2		
3		
4		
...		

Nª de falla	Fault description	Repair time
1		
2		
3		
...		

FIRM

Fig. 3. time taking record

D. Proposal Process

Fig. 4 shows in detail the step-by-step implementation of the maintenance proposal supported by three aspects that guarantee its effectiveness over time.

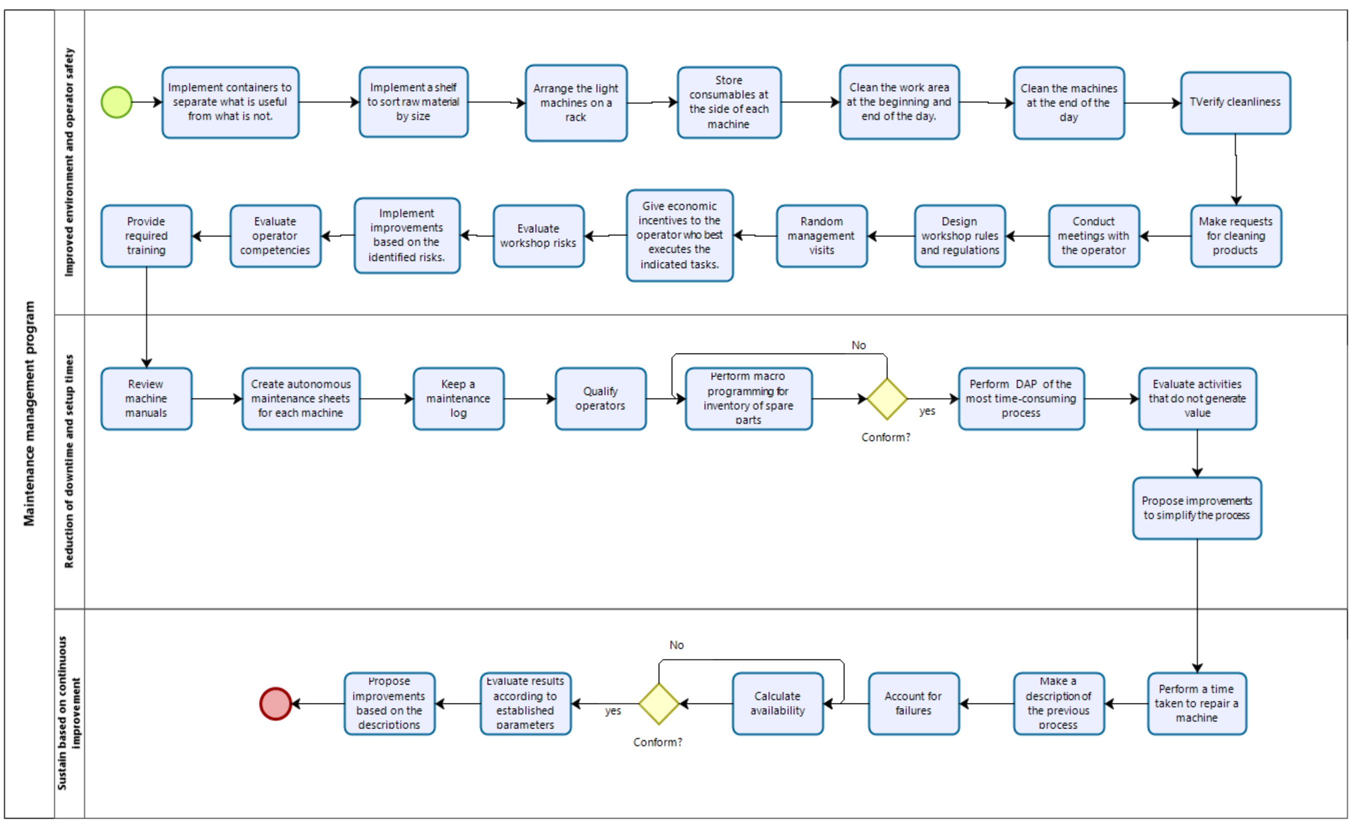


Fig. 4. Maintenance proposal implementation flowchart

E. *Model Indicators*

Table 4 shows the main indicators to be evaluated in order to have knowledge about the evolution of the implementation and improve it continuously.

TABLE 4
MODEL INDICATORS

Indicator	Delimitation	
AVERAGE TIME BETWEEN FAILURES: MTBF (increase) $MTBF = \frac{Operating\ Time}{Number\ Of\ Faults}$	Goal = 100 horas	
	Critical	Less than 30
	Risk	Between 50-80
	Adequate	Greater than or equal 100
AVERAGE TIME TO REPAIR: MTTR (Reduce) $MTTR = \frac{TF}{Number\ Of\ Faults}$	Goal = 8 horas	
	Critical	Greater than 20
	Risk	Between 12-18
	Adequate	Less than or equal 12
AVAILABILITY RATE (increase) $Availability = \frac{MTBF}{MTBF + MTTR} x100$	Goal = 87%	
	Critical	Less than 60
	Risk	Between 60-80
	Adequate	Greater than 85
TOTAL TEAM EFFECTIVENESS (OEE) (increase) $OEE = availability\ X\ Performancer$	Goal = 86%	
	Critical	Less than 60
	Risk	Between 60-80
	Adequate	Greater than 85

IV. VALIDATION

In this investigation, the arena software will be used to validate the time reduction when repairing machinery in the organization in order to obtain the mean time between failures (MTBF) and the mean time to repair (MTTR). With these data, availability can be obtained. Finally, it will be possible to compare the values before and after the implementation.

In Table 5, a brief summary of the components within the system is made that will allow obtaining the total repair time and the number of failures in a period of one month. It is worth mentioning that the first two components of recording and diagnosing are not found in the initial model since there is no history of machinery records. However, within the implemented Arena, through planned maintenance there will be a record of each machine and a more accurate diagnosis can be obtained.

TABLE 5
EXPLANATION OF THE COMPONENTS OF THE SIMULATION

Components of the simulation	Explanation
Arrival of a machine incident	The process starts with a machine incident in the workshop, either due to engine failure or the necessary replacement of a spare part.
Record incident	The incident is recorded in order to relate it to the view of the specialist and the autonomous maintenance performed.
Perform diagnosis	The reason for the failure is sought on the basis of the maintenance performed and the correct fulfillment of these.
Can the operator repair it?	Once the diagnosis is established, it is divided into whether the operator can repair it or a technician is required.
Check spare parts in stock	When choosing the route of repair by the operator by the operator
Are there spare parts in stock?	The question is asked, does the spare part exist?
Buy spare parts	If not, the spare part must be purchased.
Start repair	Once the spare part is available, the operator performs the repair.
Check repair	The machine is turned on and the repair is evaluated.
Is it compliant?	Ask if it is compliant. If it is not, it must be taken to a specialized technician. If it is compliant, the machine can be used again.
Is it transportable?	When the repair route is chosen by the operator and the technician, the machines should be classified by size, so that if it is light it should be taken to the technician. Otherwise, the expert should go to the technician.
Transport to an external maintenance area	If the machine is light, it should be transported in order to minimize costs.
Request maintenance in the workshop	Since the machine requires additional transportation for its mobility, it is more cost-effective for the technician to come to the workshop.
Is the repair cost effective?	The technician must confirm if the machine has a solution or if it is more cost-effective to buy a new one.
Remove equipment from workshop	The equipment is removed from the workshop if the repair cost is similar to the price of a new machine.
Repair by expert	The technician proceeds to repair it
Check	The correct operation is verified in the workshop
Repair compliant?	The workshop evaluates the conformity, otherwise the warranty is invoked.

To record the data and perform a diagnosis, planned maintenance and SMED have been taken into account. The latter, the operator having greater knowledge of the machine, will allow him to more easily identify the problem. Planned and autonomous maintenance provided a reduction in incident arrival times and their severity. Therefore, a greater number of incidents was obtained that will go to the side where the operator can repair it and a lower number on the technician's side. By having a greater order product of the 5S, it will be possible to easily identify the spare part that is needed.

Likewise, through planned maintenance, the probability that the part will be in the warehouse will be greater. Likewise, the probability of success in the repair by operator will be greater. Regarding the machines that need a replacement, 1 was obtained in a month, which shows an improvement compared to the 5 of the previous model.

TABLE 6
IMPACT OF THE PROJECT ON THE INDICATORS

	Before	After
Time available (H)	140	140
Stopped hours	70	57
Total hours worked	70	83
# Corrective maintenance	15	15
MTBF	4.67	5.53
Repair time	28.21	16.1
MTTR	1.89	1.07
Availability	71.13%	83.75%

Within the indicators presented in Table 6, the MTBF was 5.53, which is within the adequate range. The MTTR obtained was 1.07, so it is positioned within adequate. Finally, the main indicator of the research is above expectations. Therefore, the mean time to repair (MTTR) decreased and the mean time between failures (MTBF) increased. Both indicators show an increase in availability. The final availability obtained from the simulation was 83.75%, which means an increase of more than 10%. This last indicator shows the situation of an SME that has a great margin for improvement as it does not initially have a maintenance model. It is worth mentioning that this percentage can improve and reach the level of larger companies, which is more than 90%.

V. CONCLUSION

For data validation, a simulation has been developed in Arena of the time in which a machine takes to go through the maintenance process. Two paths were established within the system, on the one hand, when the operator can repair it with a substitution or if a technician is required. Subsequently, the MTBF and MTTR indicators obtained are within an adequate parameter. In addition, based on this, an availability of 83.75% was calculated, which is more than expected, since an increase of 8% of the initial availability was initially proposed. However, mainly due to the reduction of times in the shortage of parts and consumables, the effective fulfillment of the expected autonomous maintenance and the monitoring of expected results had repercussions in increasing projected availability by 3.75%. It should be noted that, being an SME, it has never relied on any methodology, so by making it a participant in this project, it is much more prone and flexible in increasing its availability.

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