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Increased machine efficiency through a production model integrating Lean tools and the ADKAR model in an SME of the metalworking industry

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Abstract*– Each country's metalworking industry has much economic development, providing companies with jobs and new products. However, companies have different problems in improving various aspects such as production, quality, and delivery times, among others. Therefore, to solve these problems, this article proposes a model based on implementing the Lean philosophy using different tools such as 5S, TPM, SLP, and SMED to increase the overall equipment efficiency (OEE). In addition, work was done on the mindset of workers to sensitize them through the ADKAR Model. A pilot test was carried out to validate the improvements, which gave us good results in the qualification of the audits carried out. In addition, a simulation was carried out in which the Arena software was implemented, and the result was an improvement in the OEE index of 17.60%, a reduction of 44.59 meters in operator movements, and an improvement in reducing operator effort by 88.5%. The contribution of this study can guide those responsible for the operations of SMEs in the metalworking industry that the tools of the Lean Manufacturing philosophy implemented together with the ADKAR change management model, are necessary to transform the processes as they complement each other, achieving a reduction in operational waste through the improvement of the mindset of employees by increasing their commitment to continuous improvement.

***Keywords*-- Lean Manufacturing, metalworking, ADKAR model, 5S, SMED, SLP, TPM.**

I. INTRODUCTION

The metal-mechanic sector is closely related to different industries, supplying final and intermediate goods. The most developed countries in the metalworking industry are the USA, Japan, China, Germany, and Spain [1]. The metal-mechanic industry sector is vital to the economy because it is an industrial activity that offers many jobs and products [2]. In Peru, the sector accounts for 1.7% of the GDP [3]. On the other hand, the employed EAP of the metal-mechanic sector represents 3.0% of Peru and 24.9% of the manufacturing sector [4]. In addition to the above, a growth of 6.1% has been recorded, according to the Minister of Production, due to increased construction work in the different areas [5]. The SMEs in the sector should exploit this growth, but this is only possible if they show high values in the overall efficiency of their equipment (OEE).

According to the literature, the problem identified is due to three indicators. The first is Availability, which takes up the machine's operating time. The second indicator is performance, which calculates the theoretical time of products produced to the operating time. Finally, the quality indicator calculates the number of parts without defects to the quantity processed [6]. A case study observed is that of a company in Lima, Peru. Among the causes that negatively affected the OEE were tools' setup and adjustment time, activities performed incorrectly, and equipment failures [7]. In another research, the problem of a metalworking company located in Ireland is also observed, where high setup times, high equipment downtime, low production output, and non-standardization of processes negatively affect the overall equipment efficiency [8]. The shows mentioned above that metalworking companies have low performance, Availability, and quality rates. Therefore, it is necessary to investigate new solutions to these recurring problems.

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In this context, it is necessary for companies in the metal-mechanical sector to become more efficient and thus increase the OEE index to meet the standards. Due to this, a case study was chosen in which the problems of low production time efficiency, serious planned downtime problems, inadequate working methods, high distances traveled by the operator, equipment failures, high setup times, and machine stoppages are reflected. In this sense, to eliminate the problems, an improvement model was developed with the help of tools with the Lean philosophy, including 5S, SMED (Sigle Minute Exchange of Die), TPM (Total Productive Maintenance), and the SLP (Systematic Layout Planning) tool. In addition, by integrating the ADKAR model as a major change in employee awareness, improvements will be achieved more effectively and more quickly. This research was developed through the analysis of successful cases, which presented problems like the study analyzed. In fact, the present research combines tools from the Lean philosophy in the production line of the Pull strategy, which is why the present analysis will be carried out.

This scientific article will include an introduction, state-of-the-art, contribution, validation, discussion, and conclusions.

II. STATE OF THE ART

A. The impact of Lean Manufacturing on OEE in SMEs in the metal-mechanical and similar sectors

According to research, implementing the Lean Manufacturing philosophy consists of several tools to increase productivity, reduce setup times and reduce machine failures, among other improvements [9],[10]. Within the objectives of implementing these tools, we find several improvements, starting with applying these tools in the organization. The application and purpose of these tools are to increase safety at work, improve efficiency in area controls and improve the work culture, among others [11],[12].

Previous analyses show positive results from applying the Lean Manufacturing philosophy, with a 50% improvement in changeover steps and a 60% improvement in setup times [11]. In another investigation, a 43% reduction in total changeover time and a shift improvement of 55% to 76% were achieved [13]. In another case study, OEE increased from 64% to 78% [10]; similarly, in another investigation, a 13% increase in OEE and a 48% reduction in setup times were achieved [14].

B. SMED applications in the production processes of metal-mechanical and similar SMEs

According to previous research, the SMED tool is one of the most widely used lean manufacturing techniques for setup time reduction. It reduces equipment downtime and increases production throughput [15],[16]. Therefore, one of the main objectives of the SMED application is to reduce machine setup time [17]. In doing so, it aims to increase the productivity of machines or machine lines, decreasing machine downtime and reducing labor costs. In addition, this tool maximizes the Availability of the production line to minimize bottlenecks [15].

With the analysis of the research, we can observe that one company achieved a reduction in internal configuration time from 1 hour and 44 minutes to 27 minutes and 49 seconds, improving the OEE to 73% by the availability indicator [16]. Furthermore, it was also observed that the configuration time is reduced by converting internal activities to external ones, achieving a 40% reduction [17].

C. 5S applications in the production processes of metal-mechanical and similar SMEs

According to research, implementing the 5S tool reduces downtime and non-value-adding operations, increases efficiency, and helps find faults on the production line faster [18],[19].

With the analysis carried out in the research, it could be observed that a company had a better organization of the parts, helping to improve the search time. In addition, they increased Availability from 95.9% to 97.1% in complementation with the TPM tool [18]. In another investigation, the organization and location of materials in a company's cabinets were improved, helping to identify the type and size required quickly. In addition, a 70% reduction in the time necessary to locate materials was achieved by improving the stock with the Kanban tool [20].

D. Total productive maintenance in the processes of metalworking and similar SMEs

The TPM tool optimizes industrial processes and maximizes equipment performance to increase productivity [21],[22]. Over time, the importance of maintenance and its management has been changing, assuming greater importance in a company to ensure machine availability and optimize reliability, costs, and safety [23].

The implementation of TPM will be carried out with the workers' support, considering that a company depends largely on machines. The aim is to avoid the six significant losses that can occur due to the reduction in operating speed, loss of time in adjustment and loads, and losses due to breakdowns, among others [21]. With the analysis of the research carried out, there was evidence of an increase in OEE by implementing the TPM tool to 82.75%, reducing the percentage of losses due to speed reduction by 44.79% of total losses [24]. Also, a reduction in unplanned hours, an improvement in production of 33.21%, and an increase in production capacity of 10.7% were found, resulting in improvements in OEE indicators [25].

E. SLP applications in metal-mechanical similar SMEs

The SLP tool is the best method for enterprise design. It improves productivity by reducing downtime and work-in-process inventory [26]. In addition, the SLP method is applied to optimize the design of existing machines and reduce waste. This method improves material flow and better utilization of plant space [27].

With the analysis of previous research, positive results are shown regarding the application of this tool. In one of them, a reduction of the material flow distance was found when traversing from 1,440 meters to 970 meters, and the layout design was found to be cost-effective, as the revenue is expected to increase by 7% once the improvement is applied [28]. In addition, a more organized production line, closer relative travel distances between areas, and more organized standard operating procedures were also found [29]. On the other hand, another study found a 7% improvement in OEE, a 57% decrease in setup times, and a 62% reduction in operator effort [30].

F. Applying the ADKAR model for culture change in the workforce.

ADKAR is a tool that different companies use to make a change for one or different people, increasing productivity and improving working conditions [31],[32]. One of the main benefits of this model is the reduction of workers' resistance to change as the change is more subtle and an obligation [33],[34].

With the analysis of research conducted on the study of the ADKAR model to make a cultural change in different types of sectors, it could be observed that managing an organizational change improves technology innovation, training, and changing the mentality of 150 people [35]. In addition, other research found that the ADKAR model's development increased productivity by 19.83% and reduced risk levels in the workplace by 54% [31].

III. INNOVATE PROPOSAL

A. Basic model

This work is inspired by a productivity improvement model, which aims to implement tools with Lean Manufacturing philosophy, such as 5S, TPM, SMED, and SLP. These will be combined to reduce downtime and procedures that do not add value to the process [36]. In addition, we also want to increase the efficiency of the equipment with autonomous maintenance, maximize the operator's participation and increase the quality of the final products [37]. Other models obtained an increase of 7 % in OEE on average, despite this increase does not meet the stated objective. Therefore, this research will start with a change in the Main Set of workers. Before implementing the Lean tools, the Kotter model will be used to manage the company's cultural change and thus increase productivity.

B. Proposed model

About the problems found in metalworking companies and similar situations in other previous works analyzed, an application model was proposed that seeks to improve productivity through the combination of tools such as 5S, TPM, SLP, and SMED because most of the models analyzed achieved an increase in OEE above the standard (85%) through their application. This research will start with a change in the mindset of workers using the ADKAR model to manage a cultural change in the workers of the company,

The proposed model is influenced by models analyzed in other research in the metal-mechanical sector, where they show that increasing machine efficiency is vital for increasing productivity. Figure 1 shows the components of the proposed model, such as the inputs, output, and phases that each proposed component will have, supported by the literature review.

C. Model components

The model has three components, each with its respective implementation phase, which will be explained in the following lines.

Component 1: Diagnosis of the current situation

The first component consists of identifying the product and its processes to analyze the VSM, finding the overall efficiency of the machines and carrying out a complete analysis of the current situation of the company to find the main problems it is facing. For this purpose, different Pareto analyses were used, as this technique helps us to know which problem to solve urgently as it affects production on a large scale. For example, in the Pareto analysis that was carried out to find out the main causes of machine stoppages, the main problem was the search for and preparation of tools and, in second place, machine failures. In addition, the possible root causes were found by applying techniques such as the five whys and the social integration technique (TIS), which were carried out with those responsible for the machining area and the operators.

Component 2: Design and development of countermeasures

The second component consisted of implementing a change of culture through the ADKAR model, in order to be able to use the engineering tools to solve the problems of the company's current situation. By implementing this model, a better understanding of the new standards and standardised work proposed will be achieved through the application of the engineering tools applied. The first phase consisted of sorting and eliminating unnecessary tools in the workplace in order to tidy them up and achieve a clean workplace. With the help of the assignment of each area, we can identify which tools are not placed correctly and finally an audit will be carried out to observe the compliance with the 5S tool steps. The second phase is the reduction of the fine-tuning. The SMED tool will identify the internal and external operations of the operator and the machine, converting the internal activities into external ones in order to document, train and communicate the change to the work team. On the other hand, as a third phase, the application of the TPM tool was chosen, which starts with the collection of data from the machines and the evaluation of the existing maintenance programmes, with this a new maintenance plan will be defined, which considers the deficiencies of the previous programmes and proposes a management plan to monitor compliance.

As the last phase, a new plant distribution was carried out, which consisted of finding a layout proposal that considers the space available and required by the company. To evaluate new alternatives, we will consider the work areas together and the minimum travel distance for the operator, among others. In addition, economic constraints and the land area will be considered to select the best alternative.

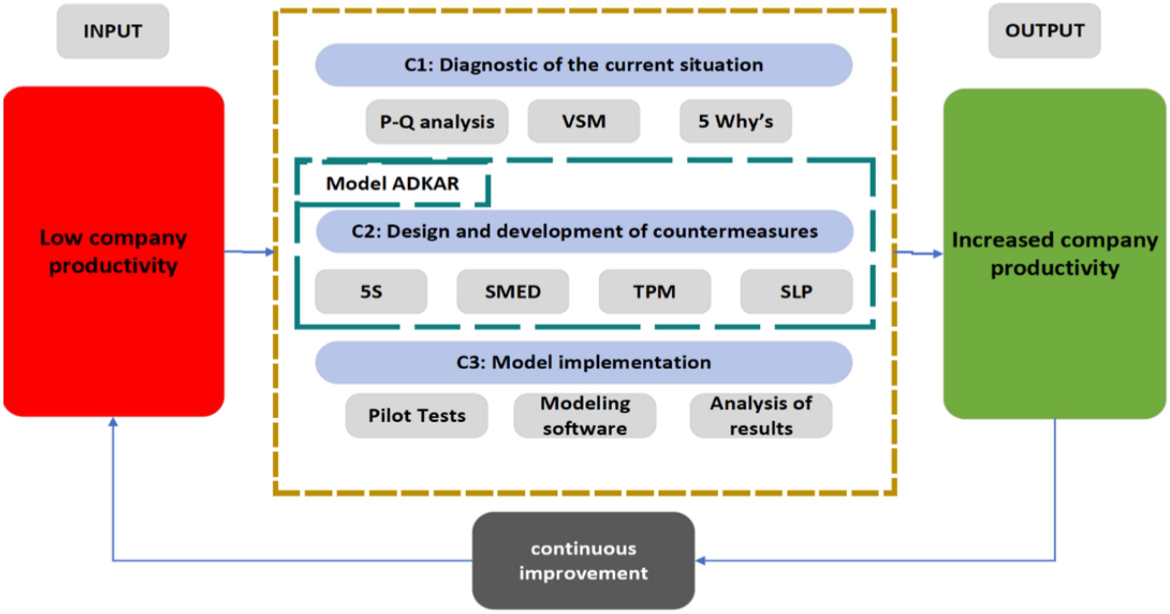


Figure 1: Proposed Model. Adapted from [12], [38], [39].

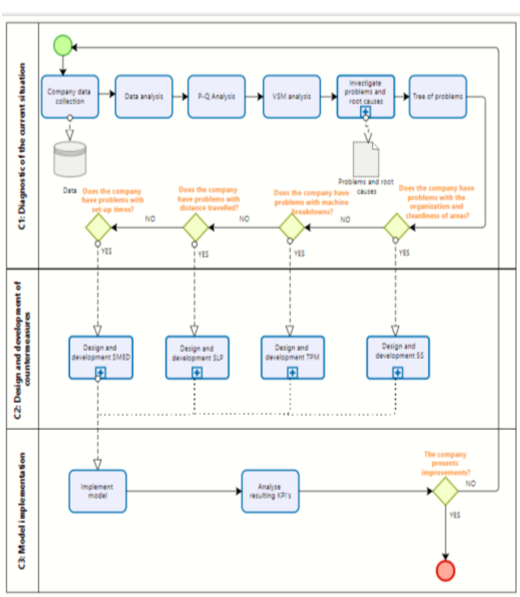
Component 3: Implementation of the model

The third model is implementing the model, which consists of analyzing the improvement proposal based on the data obtained and modeling it to observe the company's behavior after implementing the engineering tools. Finally, the results will be verified through pilot tests, simulations, and analysis of selected indicators that measure the company's performance.

D. Proposed Model Process

La figura 2 muestra el método de implantación diseñado para la implementación del modelo propuesto.

Figure 2: Proposed Model Process



E. Indicators of the Proposed Model

In the present investigation, the following indicators were used, to be able to observe that the objectives were met within formulas that the company used in the calculations made are the following:

The OEE calculation was performed by multiplying the availability, performance, and quality to achieve the objective must reach a percentage equal to the world of 85% [40].

Overall Equipment Effectiveness:
Measures the actual production capacity of the machines in the company.

availability x performance x quality

Distance traveled:
Determines the total amount of distance the operator travels for the production process.

Σ(transfer distance)

Effort:
Calculates the total effort made by workers in Kg-m.

Σ(Total distance covered * weight moved)

Mold Change Time
Calculates the total time it takes the operator to change molds to produce parts.

Σ(set up activity time)

Percentage of improvement in 5S Audit:
Determine the progress in terms of the 5S tool in the production area.

Σ(set up activity time)

IV. VALIDATION

A. *Initial diagnosis*

Among the causes affecting the overall efficiency of the machines are two leading indicators; the first is availability, represented by 75.71%, while the other is performance, characterized by 24.29%.

B. *Validation of the design and comparison with the initial diagnosis*

To validate the design created, it was divided into three components, where to begin with, the first component will focus on observing the company's current situation. Through the application of the VSM, it was possible to follow the manufacturing process of a batch of parts, where it was possible to keep that the machines had low OEE values. A deeper analysis showed that the Availability was 72.40%, while the Yield was 30.56%. A separate study for each OEE indicator showed that, on the one hand, the root causes of low Availability were 24.68% due to planned stoppages and 75.32% due to unplanned stoppages. On the other hand, operational working methods were the root causes of low performance.

The second component will focus on solving the problems encountered in the company's current situation, for which different Lean tools, SLP, and the ADKAR model will be used. First, the ADKAR model will be used to change the workers' way of thinking for the company's benefit. Then the SMED tool will be used to improve the tool changeover time and the time it takes to produce a batch of product. Next, the 5S tool will observe the company's cleanliness and reduce the search for tools or materials for production. The third tool will be the TPM, which aims to carry out a new maintenance procedure in addition to different types of training for the operators. Finally, the SLP tool will be applied to redesign the plant and reduce the distance traveled by the operators.

The third component focuses on applying pilot tests and simulations, which will provide us with new data on the indicators, which will be contrasted with those found in the company's current situation.

C. *Validation of the pilot design*

A pilot test was carried out in the machining area, for which a 5S audit was first carried out to observe the current 5S status of the company.

To start with the improvements, in the first phase (Seiri), the tools were selected according to the importance of each tool, frequency of use, and time of use, among other factors. This helped me to choose the best location. Then, in the second phase (Seiton), all the materials, tools, and raw materials were ordered according to the factors mentioned above, and red cards were used so that the operators would not take too much time looking for a type of material and so that they could control the amount of material they had in stock. Finally, in the third phase (Seiso), the work area was cleaned, where the tools that were not needed in the area were relocated, waste from the plant was cleaned, the maneuvering areas were redefined, as they were unpainted, and the workers were told how to clean the work area correctly.

The fourth phase (Seiketsu) focused on developing a new cleaning procedure in the machining area, which was monitored through check sheets. Finally, in the phase (Shitsuke), the observations and recommendations at the end of the audits will be verified to find the root causes and determine what to do to resolve them, thus maintaining discipline on the operator's part. The following comparison of audit results will be presented in the figure below.

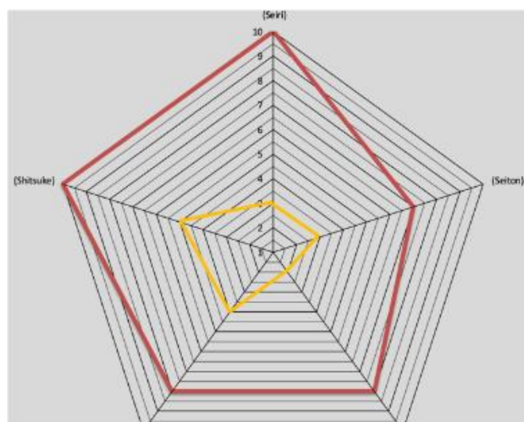


Figure 3: Final audit result

D. *Validation of the new plant design*

An effort matrix of the improved design was made to improve the plant layout, which will compare the results with the total found in the effort matrix of the company's current state. This was done to calculate the productivity variation. The new layout of the machining area is presented in Figure 4.

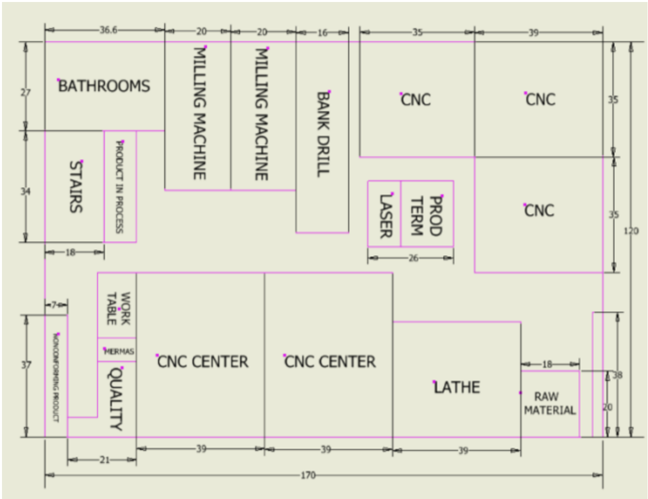


Figure 4: New design of the machining area

In the calculations performed, a total effort in the company's current situation of 43180200 kg-m was obtained, while with the new design, a total effort of 4959912 kg-m was obtained, giving a variation in productivity of 88.51%. The calculations carried out for calculating the variation in productivity will be presented below.

E. *Arena Simulator software validation design*

The Arena software was used for the simulation, with the modeling scope ranging from the arrival of the requirement from the sales area to the production management area to the dispatch of the finished product to the warehouse area. The simulation conditions considered were the input variables, the sample size, the entities, and the controlled and uncontrolled variables.

Figure 5: Simulation of the improved process

Figure 5 shows the arrival of a production requirement of 55 parts going through various activities, in which this process has six people. These are the following: production management supervisor, production management analyst, machining supervisor, machining operator, quality supervisor, and engraving and packaging operator.

Table 1 shows the proposed model's indicators, diagnosis, and simulation results.

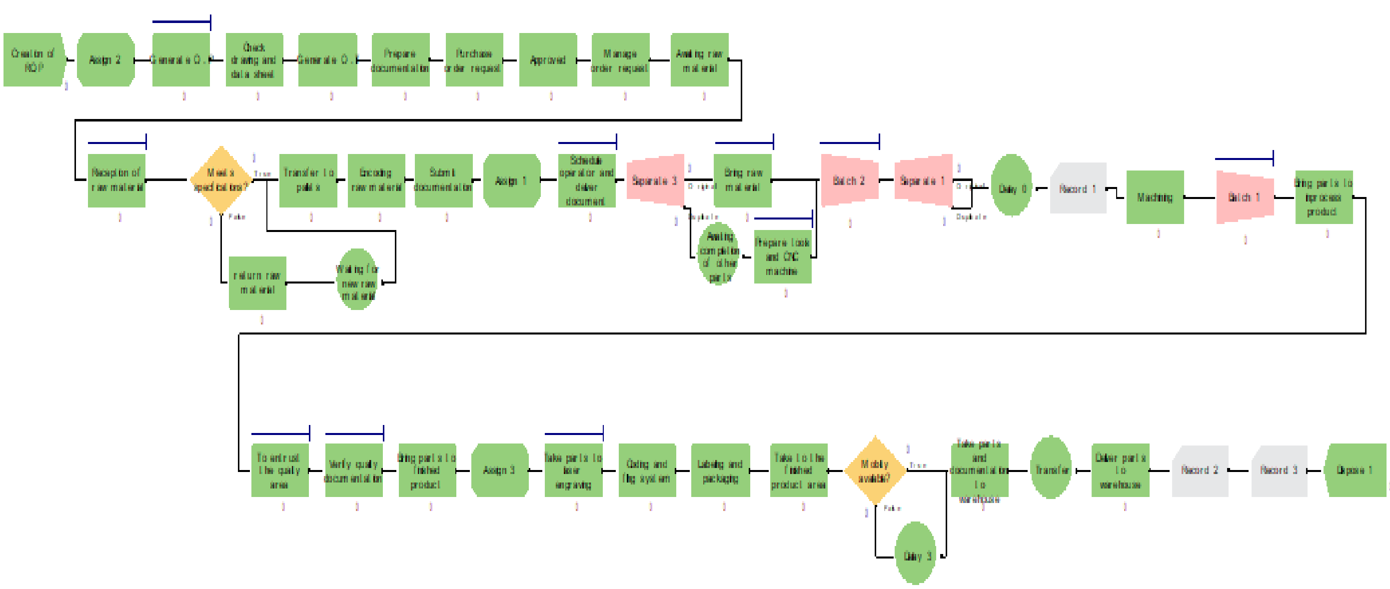
TABLE I:
INDICATOR RESULTS

Lean – SLP Tools	Indicators	Unit	As is	To Be	Improvement
SMED CNC	Time of mold change	Minutes	194.87	47.49	75.63%
SMED laser machine			43.75	16.83	61.53%
5S	Audits	Points	17	43	26 pts
TPM	OEE	%	64.14%	81.74%	17.60%
SLP	Effort	Kg-m/month	43180200	4959912	88.5%
	Distance	meters	50.8	6.21	87.8%

V. CONCLUSIONS

Through the correct application of the 5S, SLP, SMED, TPM, and ADKAR tools, it was possible to solve the different main problems in the problem tree; likewise, the leading root causes could be identified using the Pareto diagram were solved.

As for the other indicators, the improvement of 75.63% of the mold change time comes from transforming internal activities into external ones. The 52% improvement in the audit score and the decrease in breakdowns increased equipment availability, which significantly increased the company's OEE. Distance reduction by 87.8% and effort



reduction by 88.5% reduced downtime, improved material flow, and plant space utilization. All this demonstrates the effectiveness of the proposed model and the potential for modeling in other metalworking companies.

Based on the economic losses, a reduction of PEN 318,340.80 per month for setup costs was achieved by correctly applying the previously mentioned engineering tools. This resulted in an economic improvement of 75.6%.

With regard to the application of the ADKAR tool, an improvement in the performance of the workers was achieved, as they were able to better understand and carry out the actions and operations carried out in the production area, thus increasing production and reducing set-up times during the machining of a part.

In comparing scenarios carried out monthly, it was possible to observe different favorable results, thus demonstrating the reliability of the model so that it can be used in other improvement projects in the business environment. Therefore, in order to be able to correctly apply the model in the different sectors of the industry or the different production lines of a metal-mechanic company, it should be considered that the calculations made with the Arena software depend on the characteristics of the companies, so there will be variations in the results.

It is recommended to implement the proposed model in a company in the metal-mechanic sector, in different production lines, because the study carried out has primarily industrial machining machines.

Before implementing the model, an analysis should be made of the company's different aspects that are like the root causes found in the case study since there are cases where the causes of the problems do not come from the production area, affecting the planned results.

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