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Model for reducing defective production of PET Bottles through Lean Manufacturing

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Abstract– ***This article aims to bring out the importance of reducing defective products in a company that blows polyethylene terephthalate preforms for the manufacture of plastic bottles located in the city of Huanuco in Peru. The problem that arises with the generation of defective products is that they harm the economic and environmental aspects. Therefore, this article proposes a model for the reduction of defective production through the application of Lean Manufacturing tools. This model was developed mainly using Single Minute Exchange of Die and Total Productive Maintenance tools. In addition, integrating other tools such as Failure Mode and Effect Analysis and 5S was considered to achieve better results in reducing defective production in the company and thus eliminate the economic losses they cause. The model was validated using simulation software, and only for the 5S was a pilot carried out; the results obtained were a reduction in the level of defective production by 2.41% due to improvements in maintenance management and work methods.***

Keywords-- Polyethylene terephthalate, Defective production, SMED, TPM, Lean manufacturing.

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I. INTRODUCTION

Industries dedicated to the manufacture of plastic are considered one of the industrial sectors that are most important in any developing or developed country. That is why any effort to improve quality and productivity can generate a considerable contribution to the service of society and the nation. Therefore, to be globally competitive, it is necessary to supply products and services with good quality, cost, time, and speed to stabilize the market [1]. The National Society of Industries [2], affirms that 76% of the business fabric of the plastic sector in Peru is made up of micro-enterprises, while small companies represent 18%, these being the sizes of companies with the greatest representation in the year 2020. Likewise, the production of plastics increased by 17.8% compared to what was obtained in the situation before the pandemic, which shows that in 2021 a positive performance was obtained for the sector.

According to the reviewed literature, in the cases of studies related to the plastic molding process, there are constant problems related to the generation of defective products, which implies the waste of resources that affect the environment and produce economic losses. On the other hand, studies show that the integration of Lean tools provides a more detailed analysis for optimal improvements compared to using only a traditional method [3].

The motivation of the proposed research is to provide a model for the reduction of defective production in those micro and small companies with low economic resources so that they can obtain favorable results in the shortest possible time and at an investment cost according to their possibilities for implementation. of continuous improvement.

This article comprises the following: Section 2 focuses on reviewing other research cases that apply Lean tools according to typologies. In section 3, the model is developed and the description of each component of the model is presented. Section 4, the proposed model is validated in the referred company through pilot test methods and simulation. In the final section, the results obtained from the implementation.

II. LITERATURE REVIEW

A. Reduction of the level of defective production

Concerning the concept of generated waste, leading authors were identified in different areas who proposed solutions to a certain process like the research problem that is about plastic molding. In one case the author relied on an integrated Lean Green approach through the Deming cycle to increase efficiency and established diagnostic tools for operations based on waste. This obtained a reduction of defects in 43% of its production of pallets [4]. Likewise, in a case study in India, they decreased the level of defective products that they presented during the production process with the same Deming cycle model. With a result of 13.8% of its total resin production [5]. Moreover, it is important to mention a case study that produces PET plastic containers for bottled tea products, which presents different types of damage during the production process, the highest percentage being defective products, representing 48.7% of the main problems. This corresponds a 1.18% of annual defective production. Accordingly, this case study apprises the relevance of the problem generated by defective production in companies that manufacture PET plastic containers [6]. However, it was determined that the 5S tool and the training of personnel are the most commonly and implementation in companies to reduce the level of defective production [7].

B. Total Productive Maintenance to reduce machinery downtime

TPM is a tool that involves all employees of an organization intending to maximize efficiency and in turn eliminate waste, which is based on a process of continuous improvement.

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Focused on increasing the overall equipment effectiveness of machinery in terms of performance, quality, and availability [8]. This is demonstrated in a case study of a packaging company that needs to improve the effectiveness and performance of its production equipment through a sequential TPM scheme and integrates 5S with safety, health, and environmental initiatives. This is the basis of the TPM like the 5S+1 or 6S. In this way, an OEE of 62.6% was obtained as a result.

This means that there was an improvement in the efficiency of the equipment since it exceeded the target of 50% and 27.8% representing the reduction of defective parts [9]. On the other hand, in the manufacturing industry, an author proposed a work method through a TPM strategy to reduce the number of machinery breakdowns with an autonomous maintenance management plan and preventive maintenance. This significantly reduced damage failures by 38% in CNC milling centers and 23% in CNC lathes [8]

C. *Single Minute Exchange of Die to reduce changeover times*

The SMED method is characterized by improving the configuration time of the equipment transforming the internal configuration into an external one and that is done in less than 10min. The internals is those processes that can be executed while the machine is inactive and the external when the machine is working [10]. There are case studies that apply models integrated with the SMED, obtaining better results. One of them is a proposal by an author, in which he integrates the SMED with the Failure Mode and Effect Analysis.

This consists of reducing the external times and the failures of the causes and effects of the internal activities are defined for an identification of the risks in the FMEA that is equal to or greater than the average of the evaluation that is carried out. This proposal obtains an improvement of 48% due to the reduction of the configuration time [11].

In addition, in another case, it is shown that, through a systematic approach, the author proposes a model for the continuous improvement of setup times with the integration of SMED and Value Streaming Mapping to eliminate faulty production. Based on environmental, economic, and social criteria related to the setup for sustainable mapping. From this, it was obtained that there was a reduction of set-up times by 85.7% in cabinet foaming process activities.

D. *Lean Manufacturing to improve the efficiency of resource use*

It was determined that authors integrate other philosophies with Lean Manufacturing to increase the efficiency of the use of resources in different industries, in which tools such as Kaizen, 5S, and Value Streaming Mapping are mentioned as the most widely used in manufacturing companies. as for the reduction of solids [12]. In a relevant case, the author proposes an algorithm to use lean manufacturing methods such as VSM, Kaizen, 5S, Poka Yoke, Job Observation, Jidoka, and Total Productive Maintenance. From this, it is obtained that the waste classified as movements were reduced by 1.29 seg/kit with a time gain of 18.06 seg/kit. Likewise, there was a benefit in the cycle time due to its reduction to 13 sec /kit [13].

Of these relevant concepts in the literature review, case studies apply solution tools and the model or method that they apply. It was established that for the problem of the Huánuco case study, integration of Lean Manufacturing tools will be applied to achieve a reduction in defective production in the production process of PET bottles.

III. THE PROPOSED MODEL

The proposed model of this research is presented in Figure 1 to reduce the defective production of PET bottles. This model is developed based on the Thorat and Mahesha model. [14], where the Total Productive Maintenance methodology is used to increase the general efficiency of the machinery in a company dedicated to plastic injection molding, for which the Mean Time Between Failures, Mean Time to Repair, and

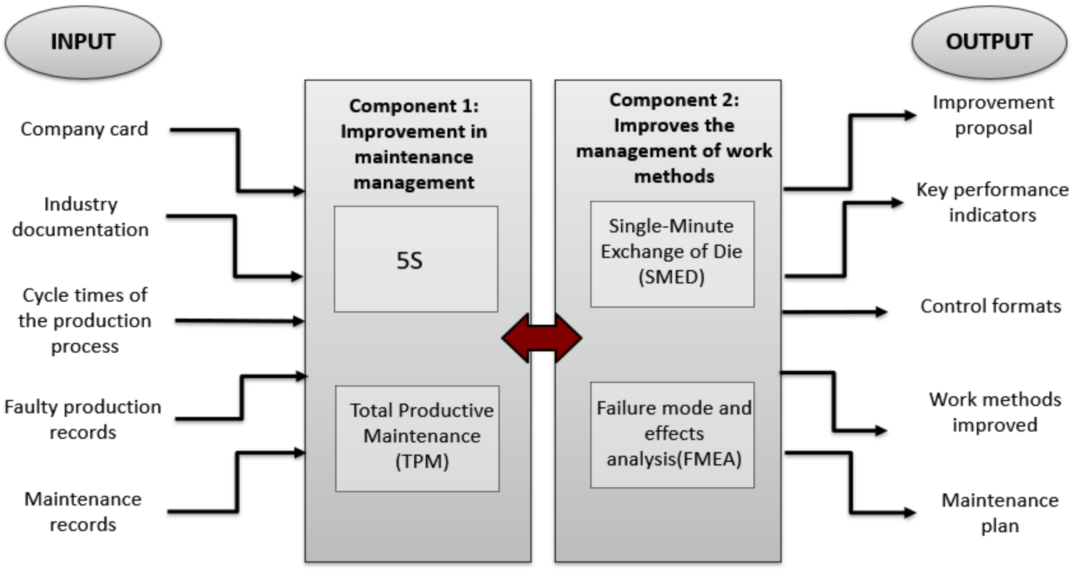

Fig. 1 *Proposed model*

Overall Equipment Effectiveness indicators are used to evaluate the performance of the Proposed Solution. Likewise, Yazici was used as a reference [11], where the Single Minute Exchange of Die methodology is used for classifying activities, outsourcing activities, and implementing corrective measures to reduce the time of external activities. In addition, Failure Mode and Effect Analysis is used to reduce the time for carrying out internal activities. With the knowledge obtained from the previous literature review, the model presented in Figure 1 has been built.

A. Proposed model

1. Improvement in maintenance management

According to Pinto [8], Total Productive Maintenance has 8 pillars that aim to eliminate losses and reduce machinery downtime. Therefore, for the present investigation, the following pillars will be used: Elimination of main problems, autonomous maintenance, planned maintenance, and training. Therefore, for the initial deployment of this methodology, an environment must be available for its implementation. According to Chandrayan [15], 5S is a technique used to establish an organizational culture based on order and cleanliness, so the 5 steps that comprise the technique must be followed: Classify, order, clean, standardize and keep.

2. Improvement in the management of work methods

According to Yazici [11], Single Minute Exchange of Die is a tool that aims to reduce Set-Up times through the development of 5 sequential steps proposed in the SMED methodology, which are: Determination of the initial state, separating internal from external activities, converting internal activities into external, apply corrective activities to reduce the time of internal and external activities and create action plans to eliminate causes of delay. Also, Yazici [11] integrates the Failure Mode and Effect Analysis tool to identify and eliminate possible causes of machinery failure to avoid damage to its operation by prioritizing activities based on the RPN, which is calculated based on the occurrence of failure, the probability of failure, and detection.

B. Model detail

The model is made up of three methodologies for continuous improvement. Accordingly, it is necessary for the quantitative registration of the company under study and documentation of the sector.

As can be seen in Figure 1, component 1 develops the following: The first methodology corresponds to the application of the 5S technique, which begins with the formation of the 5S committee that will oversee managing the manual and the execution of the 5S program. This committee is appointed by senior management and is made up of the production manager, sales manager, and production supervisor.

The execution of the 5S methodology is divided into 5 stages, which begin with the classifying stage. The application area is delimited in this stage, and the classification criteria are established. Based on this, a decision is made to organize, repair, discard, or transfer the object. The second stage corresponds to the organization of the workspace. To do this, useful elements obtained from the previous stage are in designated spaces and labeled according to the frequency of use, so the tools with the longest use time must stay within reach of operators. In addition, the work areas are delimited so as not to obstruct traffic routes. The third stage consists of cleaning the facilities, so cleaning tasks must be planned for their execution. At this stage, workers must take responsibility for cleaning their workstations. The fourth stage corresponds to standardization, which implies the establishment of responsibilities, the continuous verification of the implementation of the first 3 stages, the development of preventive measures, and the identification of opportunities for improvement. Finally, the fifth stage is to maintain the changes made in the previous stages. To this end, activities are established to foster employee commitment, and discipline is promoted.

The second methodology corresponds to the application of Total Productive Maintenance, which begins with the determination of losses and main problems, this is done through a Pareto diagram to highlight the most recurring problems. Then, we investigate the causes of the previously identified main problems using "the 5 whys ". Next, corrective actions are proposed based on the previously identified causes. These corrective actions must be standardized, so standard conditions are established in the production lines to facilitate the learning of new habits by workers. The corrective actions that were implemented allow the development of autonomous maintenance since it is possible to implement cleaning and maintenance procedures in work routines.

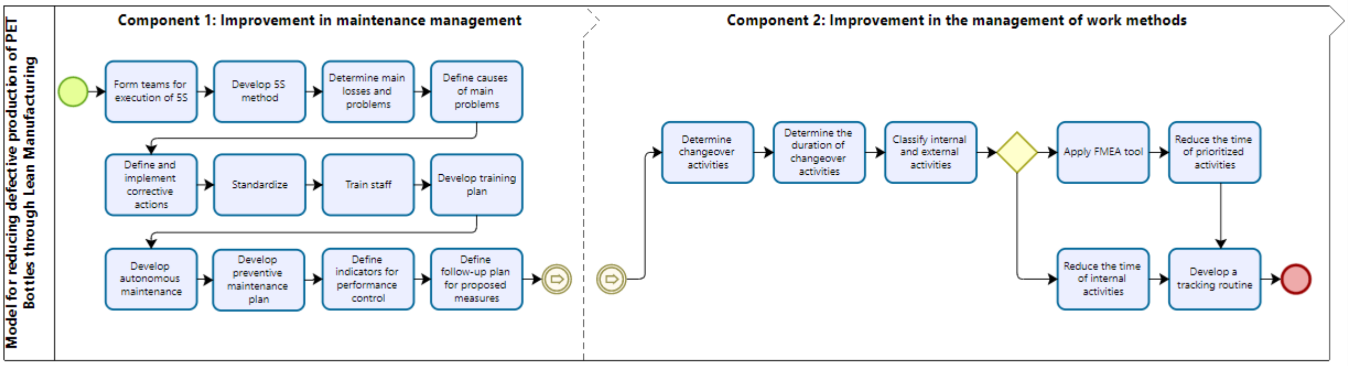

Fig. 2 *Lean Implementation Flowchart*

This is done through a cleaning checklist where compliance with their tasks is verified, as well as the level of compliance is calculated. Then, preventive maintenance planning is carried out to ensure the availability of the machinery, as well as preserve its useful life. Consequently, a maintenance schedule is established based on the calculated failure frequency of each piece of machinery to avoid unscheduled stops in the production line. In addition, workers must be instructed to timely report unforeseen failures to be considered within the development of the maintenance plan. Finally, indicators are established for performance control based on the proposed improvements, and the monitoring plan is defined according to the measurement frequencies described changeover activities are identified.

In the second component shown in Figure 1, the third methodology corresponds to the SMED is developed, where the identification of changeover activities is carried out. Then, these identified activities must be measured with the use of a stopwatch to show the current situation. In addition to this, those activities that can be outsourced must be identified to avoid stopping the production line. Outsourced activities should be prioritized by applying the FMEA tool and calculating the risk priority number. Finally, corrective measures are proposed for prioritized external activities to reduce their duration.

C. *Process proposed*

It can be seen in the flowchart presented in Figure 2, the sequence of activities to be carried out for the implementation of the model. Where the model is divided into 2 phases that are: Improvement in maintenance management and improvement in the management of work methods.

D. *Model indicators*

The indicators of the proposed model were determined according to the data collected from the company under study and according to the literature review to verify if there were corresponding improvements according to the root cause of the problem.

TABLE I
Main indicators of the model

Indicator	Formula
MTTR	Total time to repair / number of failures
Performance (%)	Cycle time x number of units processed / operating time x 100%
Availability (%)	Operating time / planned time x 100%
Quality (%)	(Actual production – Defective units)/ Total production x100%
OEE (%)	Performance x Quality x Availability (%)

IV. VALIDATION

For the proposed research model, two validation methods were determined: pilot test and simulation. Therefore, the first stage of the maintenance management improvement component will be developed through a pilot project to monitor the 5S methodology as a support tool for Total Productive Maintenance.

This methodology, which is based on the maintenance process of the machines, will be validated through a simulation model in the Arena Simulation software. Likewise, the second stage of the work methods improvement component, which is mainly made up of the Single Minute Exchange of Die method, will be carried out with the same software mentioned, considering the changeover time process.

A. *Initial diagnostic*

1. *Component one: Improvement in maintenance management*

- Initial pilot test of the 5S methodology:

To diagnose the current situation, it was carried out in 4 weeks, which the selected area will be the main worktable of the company under study as shown in Figure 3 all the frequent operations related to the maintenance process and changeover time take place in this table, such as basic repairs, tool use spare parts and data record manuals. This situation in the area makes it difficult to carry out the activities of the operators for that reason the tools and spare parts are disordered on the worktable.

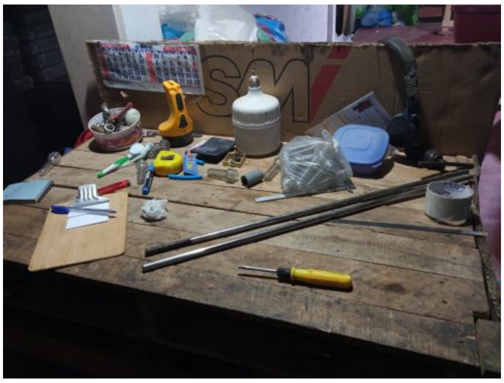

Fig. 3 Current situation of the main worktable

To demonstrate the impact generated by the search for tools, it will be carried out through a time measurement, since it is essential for both the maintenance process and the changeover time. The 5S supervisor will oversee measuring time using a record sheet format. From this, it was obtained that, currently, the average search time in the maintenance operation is 2.30 min and the changeover is 3.08 min.

- Total Productive Maintenance simulation model of the initial situation

In this simulation model, the corrective maintenance process was considered since currently, the company under study presents unscheduled stops in the machinery, which causes interruptions in the production line and prolongs the duration until spare parts are obtained from the warehouse or purchased parts so that they can be repaired. The data collection was carried out to identify the activities, attributes, and entities of the process. In this way, the Input Analyzer software will be used to identify the distribution fit and the system will be represented using the Arena Simulation software as shown in Figure 4.

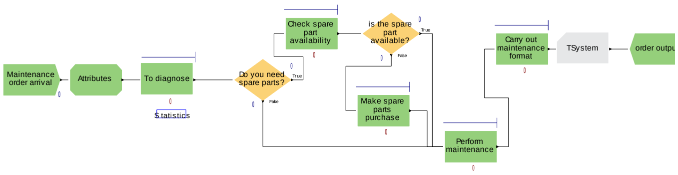

Fig. 4 System representation of the initial maintenance process in the Arena Simulation software

It was identified through the software report that the mean service time in the queues is not significant as a result the values are less than 0.5 minutes. Therefore, the average permanence times of the system will be considered, which is 39.67 min.

2. *Component two: Improvement of working methods*

- Single Minute Exchange of Die simulation model of the initial situation

This simulation model was developed based on the activities of the current changeover time process according to the cycle times of the PET bottle with the highest demand of the company under study. This process begins with an arrival order according to the morning, afternoon, and night shifts, generating three orders for the three blow molding machines. Likewise, twenty activities were identified that have not been classified as internal and external, which causes delays in the process. Through the data collection, the input data treatment was carried out with the Input Analyzer software and as shown in Figure 5, the representation of the system was made in the Arena Simulation software of the current changeover time process.

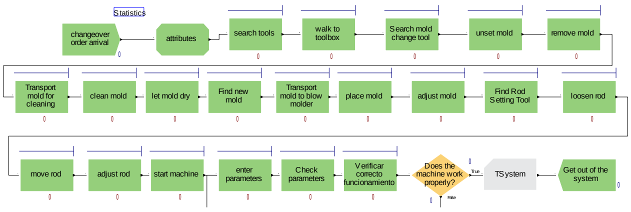

Fig. 5 System representation of the initial changeover time process in the Arena Simulation software

Likewise, it was identified through the software report that the average service time in the queues is not significant as a result the values are less than 0.5 minutes. Therefore, the average permanence times of the system will be considered, which is 129.55 min.

B. Validation design: Improvement proposal

1. *Component one: Improvement in maintenance management*

- 5S pilot test after implementation

The design for the pilot test of the 5S methodology is classified into three phases for its execution, which the production supervisor will oversee complying with the schedule.

In phase one, in Seiri or classify, unnecessary items will be classified by labeling them with red cards and recording them for future observations. In Seiton or order, an order of the elements was established according to their frequency of use to provide greater ease to the operator when carrying out their activities. This was categorized on the workbench as cleaning, office supplies, tools, and maintenance. In Seiso or cleaning, each activity that is related to cleaning will be according to the frequency of execution and the availability of the operator both at the worktable and in the areas close to it.

In phase two, in Seiketsu or standardize, criteria will be established to establish procedures for an adequate classification of tools on the worktable and delimit areas to prevent them from hindering the operator's activities. In phase three, Shitsuke or discipline, an implementation control will be carried out through an evaluation of 5S through a checklist to demonstrate the improvements in the area.

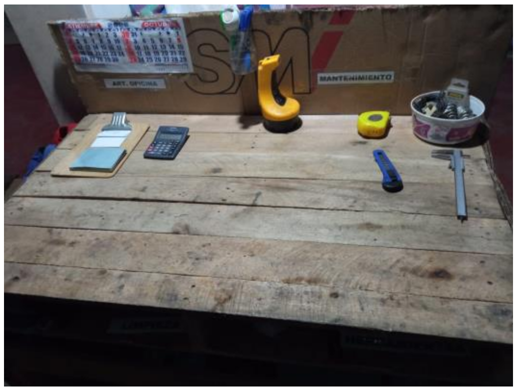

Fig. 6 Workbench area after 5S implementation

As shown in Figure 6, the main worktable is ordered and duly labeled. From this, scores are obtained in each evaluation of classification, order, cleanliness, standardization, and discipline based on a comparison of what was obtained before and after the implementation.

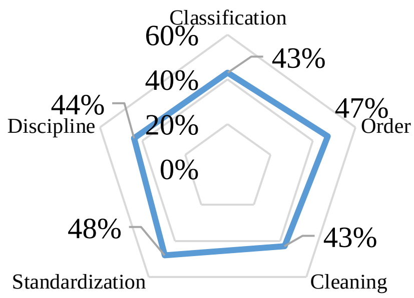

Fig. 7 Workbench area after 5S implementation

As a result, it is demonstrated in Figure 7 that increased the level of 5S by 44.83% after the implementation of the 5S pilot test.

In addition, according to the variable of interest of tool search times, a reduction in time was obtained after the pilot test, such as operations with maintenance in 1.50 min and changeover to 2.21 min.

- Proposed Total Productive Maintenance Simulation Model

In this model for the proposal, preventive maintenance was included in the process with the probability that corrective maintenance occurs. In consideration of that, what can be seen in Figure 8, the entities in the system representation of the Arena Simulation software were increased.

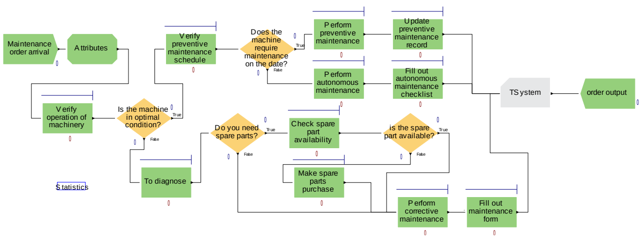

Fig. 8 System representation of the improved maintenance process in the Arena Simulation software

This begins with the maintenance order and with the verification of the operation of the machines to determine if preventive or corrective maintenance is required. If it is operational, the preventive maintenance schedule is verified so that the operators can carry out the preventive or autonomous maintenance as appropriate so that when it is completed the records are updated or the checklist of the maintenance format is filled in respectively. If the machine is not in optimum condition, it is decided to carry out corrective maintenance. Using this model, input data was processed for the use of the Input Analyzer software and distribution adjustments. Likewise, it was identified through the Arena Simulation software report that the mean service time in the queues is not significant as a result the values are less than 0.5 minutes. As a result, the average permanence times of the system were considered, which is 37,156 min.

2. *Component two: Improvement of working methods*

- Proposed Single Minute Exchange of Die Simulation Model

The model proposed for the SMED was developed by outsourcing those activities that can be previously executed. That is why in Figure 9 the representation of the system in the Arena Simulation software has reduced by 50% of its activities compared to the current situation.

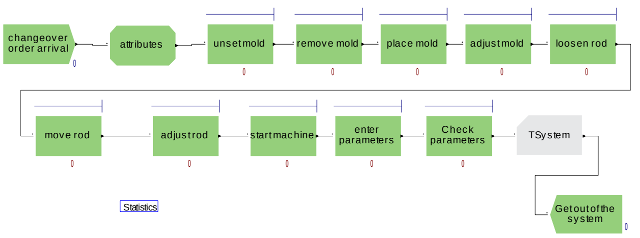

Fig. 9 System representation of the improved changeover time process in the Arena Simulation software

Previously, input data processing was carried out in the Input Analyzer software to adjust the distribution of the system. Then, it was obtained through the Arena Simulation software report that the mean service time in the queues is not significant as a result the values are less than 0.5 minutes. As a result, the average permanence times of the system were considered, which is 63,724 min.

C. Initial diagnostic vs. Validation design

1. 5S pilot test

- Variable of interest: Average search time for tools

Table II

Summary of average tool search times by type of operation

Operation type	Initial diagnostic	Validation Design
Maintenance	2.30 min	1.50 min
Changeover time	3.08 min	2.21 min

- Total Productive Maintenance and Single Minute Exchange of Die Simulation Model

Table III

Comparative summary of system times in changeover time and maintenance processes

Methodology	Initial diagnostic	Validation Design
TPM	39,672 min	37.156 min
SMED	129.55 min	63.724 min

Table IV

Indicators after validation through simulation models

Indicator	Initial diagnostic	Proposed model
Mean Time to Repair (min)	39,672 min	37.156 min
Performance (%)	70%	78.30%
Availability (%)	83%	94.89%
Quality (%)	96.49%	97.59%
OEE (%)	56.06%	72.44%
Level of defective production (%)	3.51%	2.41%

V. ACKNOWLEDGMENTS

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VI. CONCLUSIONS

It is concluded that the proposed model's reduction of changeover times was by 65.83%, and there was an increase in the Overall Equipment Effectiveness of 72.44%, which means a reduction in the occurrence of unscheduled stops of the machines was as expected. Also, with the proposed model, a 1.10% reduction in the level of defective products was obtained. It was less than the technical gap with the plastic sector of 2.33%.

On the other hand, it was not possible to exceed the international standard in indicators such as OEE, Quality, and Performance. Nevertheless, the Availability indicator exceeded 90% of the international standard with 94.80%. It is worth mentioning that the results of the OEE, Quality, and Performance were favorable, with 72.44%, 97.59%, and 78.30%, respectively, exceeding the initial percentage before implementation. As well as there was a reduction in Mean Time to Repair by 2,561 min.

Finally, by reducing the level of defective products, it is obtained that the investigation is economically viable with a net present value of S/ 101,561 and with an internal rate of return of 88.29%. Moreover, it is concluded that through different simulation model scenarios, an analysis of the impact of the different work shifts or an approach according to the execution times the useful life of the machinery could be carried out. It should be considered that the evolution of the improvement indicators can be evidenced in at least six months of project implementation.

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