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Model based on TPM to increase the overall efficiency of equipment in an oil company

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Abstract*– The palm oil industry accounts for 33% of vegetable oil production worldwide and has seen an increase in demand in recent years. Despite this, demand in Peru cannot be met because, in many companies, the efficiency of the machines is far below the ideal indicator of 85%. In the company under study, located in the Ucayali-Peru region, the overall equipment efficiency (OEE) is 73.27%, implying that the machinery is not adequately utilized. In that sense, this article shares a real experience of the palm oil industry for an improvement project evaluated with the OEE indicator through the Total Productive Maintenance (TPM), Single-Minute Exchange of Die (SMED) methodologies, among other engineering tools. The final objective is to achieve an improvement in the OEE metric up to the World-Class category of 85%. After simulating the proposed model in Arena taking as indicators the MTTR (Mean time to repair), Set-up time and downtime, a new improved OEE was calculated, which meant an increase of 14.97%, with an availability of 2.96% and a yield of 12.59%. The verdicts of this labor exposed the profit of TPM application in real world oil companies.

***Keywords*— TPM, OEE, SMED, Methods' study, AVA.**

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Abstract*– The palm oil industry accounts for 33% of vegetable oil production worldwide and has seen an increase in demand in recent years. Despite this, demand in Peru cannot be met because, in many companies, the efficiency of the machines is far below the ideal indicator of 85%. In the company under study, located in the Ucayali-Peru region, the overall equipment efficiency (OEE) is 73.27%, implying that the machinery is not adequately utilized. In that sense, this article shares a real experience of the palm oil industry for an improvement project evaluated with the OEE indicator through the Total Productive Maintenance (TPM), Single-Minute Exchange of Die (SMED) methodologies, among other engineering tools. The final objective is to achieve an improvement in the OEE metric up to the World-Class category of 85%. After simulating the proposed model in Arena taking as indicators the MTTR (Mean time to repair), Set-up time and downtime, a new improved OEE was calculated, which meant an increase of 14.97%, with an availability of 2.96% and a yield of 12.59%. The verdicts of this labor exposed the profit of TPM application in real world oil companies.

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I. Introduction

In recent years, the production of palm oil has been constantly growing. In this way, this oil could continue to expand over the decades [1]. More than 33% of the world production of vegetable oils is represented by palm oil. In this way, palm oil is consolidated as the vegetable oil with the highest global production [2].

Within the market, the demand for oils is becoming more significant every year, causing it to not be covered by national producers. Approximately, a deficit of 220,000 tons is calculated each year and this is covered with imports of other vegetable oils for a value that amounts to 90 million dollars. This is due to several factors, the most important being the low efficiency of the machines used in the oil extraction process.

To solve this problem, authors have proposed to design and build a new multi-motorized equipment that extracts higher rates of oil [3], however, applying this implies a total change of equipment's, which incurs more significant costs. That is why it is necessary to rely on the use of other techniques and/or tools in order to improve efficiency within this process. Thus, there are successful cases where TPM has been shown to be effective in increasing OEE [4]. The TPM was outlined in 13 steps grouped into 6 implementation phases using Autonomous Maintenance and Planned Maintenance, achieving an increase in availability of 13% and increasing the OEE to 62.6% [5]. Other authors implement a new maintenance model based on the TPM called mobile maintenance. This incorporates 8 pillars of the methodology, resulting more agile and dynamic. This is reflected in an increase in OEE of 17.08% and a reduction in production stoppages of 23.14% [6]. On the other hand, authors use the SMED technique in order to reduce set-up times and increase the efficiency of the equipment. For example, SMED was combined with Pre-setting systems (anticipation of device settings) to reduce set-up times in a semi-automated company. As a consequence, the OEE of the entire line increased by 17% and set-up times were reduced by 87% [7].

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Globalization has brought competitiveness to all industries, and the palm oil isn´t the exception. To ensure competitive advantage over other companies, constant improvement actions are necessary over time. In this way, waste could be reduced within the process and profitability could be ensured. The main goal is to minimize machine stoppages to increase the overall efficiency of the equipment. One of the approaches that aids to become corporations more competitive is Total Productive Maintenance (TPM). This tool could be accompanied outstandingly with SMED method, used to reduce the configuration time of a machine. One way to be successful with the TPM methodology in their One way to be successful with the TPM methodology is developing a new autonomous maintenance procedures and well-scheduled preventive maintenance plans [8]. The authors achieved higher performance indicators, such as: 23% decrease in breakdowns and 5% increase in OEE.

The article is organized in this way: after the introduction, section 2 reviews the most important literature. Section 3 describes the proposed model associated with TPM and the tools which you can work in conjunction with this methodology and how these will be used within the work. Section 4 shows the validation of the proposed solution followed by conclusions in section 5.

II. Literature review

Many research studies focused on increasing the OEE of various equipment using different methodologies adjusted by decreasing machine failures, set-up times and minor stoppages. The literature provides us with many applications in various fields. Here, just some of these studies will be discussed.

A. Overall Equipment Effectiveness (OEE)

The Overall Equipment Effectiveness (OEE) is classically an indicator developed by Nakajima in 1988 for the first time in English, used to monitor the efficiency of the machinery of a process. However, despite its wide diffusion and use, it is still evolving and adapting, giving rise to new models [9]. There is a generalization of OEE as a variant known as Overall Environmental Equipment Effectiveness (OEEE), which is a formulation exclusive to the machine level, to a system level model called sustainable overall throughput effectiveness (SOTE) [9]. The technique used is the characterization of the machine system, and the calculation of the model formulated in the research. The formulation distinguishes 4 machine formations which are series, parallel, assemblies and expansions and the possibility of combination of these. The OEE does not indicate the reason why a machine is not as efficient as it should be, it indicates which areas should be improved to improve the efficiency of the equipment [10]. In other words, this indicator is no longer used as an evaluative agent, but as a diagnostic method for identifying opportunities for improvement [11]. Once mentions that the average OEE among companies is around 60% [12], taking that into account, considering the goal of 85% as the acceptable OEE sounds realistic.

Currently, this is a concept in constant evolving and despite OEE was formulated with the idea of standardizing the calculation of machine efficiency in order to be able to compare between different companies, there are still some holes in this indicator that have not been solved. This is since, although a single formula was standardized for the calculation of efficiency, a standard method for obtaining the data necessary for the calculation was not established, leaving to each company the way of calculating the reduced speed and minor production stoppages [13].

B. Total Productive Maintenance (TPM)

Total Productive Maintenance (TPM) is a maintenance philosophy or methodology based on 8 principles called pillars. The most defining pillar of TPM is autonomous maintenance (AM) [14-15], which implies involvement of employees outside the maintenance area to accomplish minor maintenance tasks [15-16]. Furthermore, those who would involve in AM are not just plant employees but those of the entire organization [17] allowing employees to improve their skills and increase their knowledge [6].

The main use of the TPM and 5S methodology is reducing frequency and duration of corrective interventions, for example, a maintenance strategy based on the 3 pillars of TPM (planned maintenance, autonomous maintenance and focused improvements combined) with the application of the 5S that resulted in a number of interventions reduction by 38.1%, the intervention time reduction from 12 hours to 3 hours and the OEE increase by 5%. In addition, non-measurable results were also obtained such as an increase in autonomy of the teams [8].

An innovation in the field of TPM is adding 4.0 technologies calling it as TPM 4.0 which consists of 2 components: the standardization of maintenance processes and the implementation of autonomous maintenance being monitored by 4.0 technologies [18]. An improvement of 42% was obtain in the seventh week, and 88% in the ninth week, based on the number of preventive checks and the number of corrective repairs. There are some articles with the propose of modeling a low investment cost TPM methodology for medium-sized companies, for example, a proposal with 2 components, methodology design and implementation design. The first one based on theory and literature, the second one based on a VSM (Value Stream Mapping) as an evaluative agent of success of the proposal. An increase in OEE from 54.23% to 66.90% and non-measurable improvements like an increase in staff involvement were achieved [15].

An analysis of the factors about machine failures suggest the application of TPM and RCM (Reliability Centered Maintenance) applied together as a single and advisable methodology in which is possible to obtain a decrease in maintenance costs from 45000 to 17000 KDA and a decrease from 267 to 173 annual maintenance interventions [14]. Other compound methodology is TPM with Kaizen to reduce minor failures with 2 components (Training and continuous improvement process) leading to an OEE improved by 11.83%, productivity improved by 23.93% and defective products decreased by 49.50% [16].

C. Single-Minute Exchange of Die (SMED)

The Single-Minute Exchange of Die (SMED) is a working approach employed to reduce machine setup time [16] achieving if correctly implemented times of less than 10 minutes i.e., single digit [19-20]. SMED was also used to improve OEE in various industries. It has been successfully implemented in different sectors and different company sizes including the food industry [20]. In research was able to eliminate waste and non-value-added activities using SMED, the set-up time of the forging press was reduced from 209.36 to 167.09 min [6]. In addition, there is a set-up process improvement model through a conventional SMED method. Four standard strategies and a priority sequence are introduced for a conventional SMED extension step. The overall efficiency improvement is 44 % [16].

A developing of a novel SMED model that integrates traditional SMED and fuzzy failure modes and effects analysis (Fuzzy-FEMFA) methods achieve the set-up time is reduced 48% [20]. It is common using SMED with the help of the lean tools ECRS, Kaizen and Standardization to reduce the set-up time and increase the OEE. Studies shows the development based on an application of improvement by ECRS (eliminate, combine, reduce, and simplify), standardized work (SW) and OEE. The combination achieve that the Set-up time was improved by 91.6 %, OEE increased by 44.6 % and the setup activities were standardized [21].

Other possible combination is an application of a fuzzy inference system (FIS) coupled with SMED for parameter settings during changes in plastic injection molds. However, it was concluded that the high workload of configuration experts affects lot size planning; therefore, the expected benefits of SMED cannot be realized due to the lack of experts [22]. The implement Lean tools (VSM and SMED) in a company in the food processing sector, to reduce setup times on a machine and increase production capacity, enabled the reduction of set-up time related waste by 34 % and increased the production capacity of Line 1 by 11 % [23].

D. Methods´ study

On the other hand, it is also necessary to analyze the process of each activity performed within a production line. It is important to know how to identify the activities that add and not value within these processes. The identifying of non-value-adding activities (NVA) from the core manufacturing process and eliminate them by standardization of work (SW) have resulted, in previous research, in a saving of 31.6s per cycle, boosting production to 58 parts per 7hr work shift [24]. A study of times and movements to increase the productivity of the footwear production process could allow an increase in productivity of 5.49% as in former works [25].

An evaluation proposal that consisted in the reformulation of the work methodology based on the requirements of the task and its evaluation could reach a 22% reduction in the production cycle of the study station [26]. Also, a time study to calculate the cycle time of a robot assembly can determine the optimal scenario in a cycle time, for example, it aims to find a time reduction of 17.16% of cycle time that implies the possibility of increasing annual productivity by more than 17.2% [27].

III. Conceptual model

The conceptual model begins with the conceptual idea schematized in a model in Figure 1. It continues with the fundaments and details of the model. Finally, it is exposed the process and indicators to be used in the model's application.

A. Proposed model

With the purpose of increasing the OEE, a model was formulated based mainly on the TPM methodology with 2 components, this can be seen in Figure 1. The proposed model is based on 2 components: The maintenance component and the process component. All framed under the PHVA (Plan, Do, Check and Act) continuous improvement cycle. Together, both components can define the process of basic maintenance and machinery configuration (Maintenance) looking for the simplest and most profitable way to be performed (Process). In addition, the process component can also be applied to reduce the duration time of minor stoppages that reduce the time available for the use of the machinery. In this way, both components complement each other for the fulfilment of the main objective: to increase machinery efficiency.

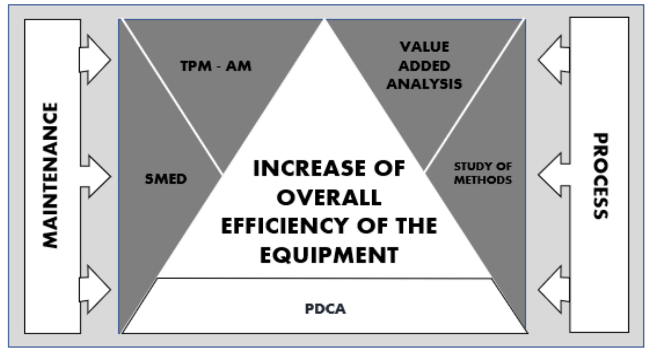

Fig. 1 Proposed Model Scheme.

It should be considered that to implement the model in a real case some information such as current set-up routines, current operation manuals and data history may be necessary. Once the proposed model is implemented, it should be possible to write an autonomous maintenance procedure, a set-up procedure, and the necessary number of minor shutdown procedures.

B. Foundation

The maintenance component refers to the maintenance techniques to be used during implementation, i.e., setup, lubrication, cleaning, adjustment of parts within the component. In that sense, 2 methodologies were established within the maintenance component to execute the activities: autonomous maintenance (MA) and SMED methodology. These 2 methodologies are statistically significant when applied together for the reduction or elimination of waste [28], likewise separately the autonomous maintenance reduces the need for interventions by the maintenance area [18] and the SMED methodology helps to reduce setup times by converting internal activities into external ones seeking to reduce setup times to a single digit [20]. On the other hand, the second process component relates the concept of time study part of the study of methods and the evaluation of added value of the VPA that in combination can be used to redefine an activity seeking to reduce or eliminate some of the 3M (Mura, Muri and Muda) [24]. Component 2 was proposed to simplify the manual processes of maintenance and to simplify the processes of minor shutdowns. In this sense, 2 methodologies were established to execute the simplification: the study of methods and AVA (Activity Value Analysis or Value-Added Analysis).

C. Model details

The first proposed artifact of the maintenance component is autonomous maintenance (AM), whose purpose is to reduce the interventions of the maintenance area that are due to basic maintenance such as lubrication, internal cleaning, tightening of parts, among others. the implementation of autonomous maintenance as the main pillar within the TPM helps to increase the efficiency of the equipment within a production line [18]. This decreases machine downtime and thus increases OEE. The second proposed artifact of the maintenance component is the SMED methodology that serves to reduce setup times for each machine. This methodology is the most common method to reduce times to less than 10 minutes [20], consequently helping to increase efficiency. SMED will support the simplification of setup activities, as well as the reduction of these activities to be performed with the machinery running. The reduction of times will increase availability which results in an increase of OEE.

The first proposed artifact of the process component is a study of methods, mainly the time study under the framework of the Westinghouse method valuation for all process to be analyzed from the point of view of time and activity reduction with an adequate time analysis. This will make it possible to know the progress in time reduction of the activities [24]. The second proposed artifact of the process component is the AVA matrix that evaluates whether an activity adds value to a given product, taking as criteria the 3M (Muri, Mura and Muda) that refer to the imbalance, overload and waste that a process may contain [24]. This in combination with the previous artifact will allow the reduction of the time of minor stoppages by modifying and simplifying the process it. In this way, the performance is increased and the OEE is increased.

D. Proposed process

The process by which the proposed model is implemented is under the PDCA framework as shown in Figure 2.

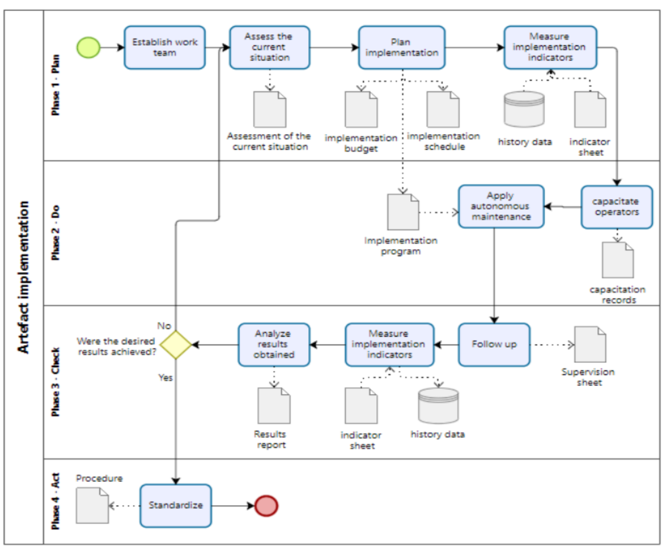

Fig. 2 Business process model and notation of the artifact implementation.

In this way the proposed artifacts will be implemented, except that the artifacts of the process component must be applied.

In the planning phase, the first thing to do is to establish the work team. After that, an evaluation of the current situation is carried out, where a record must be made to evidence this evaluation. Subsequently, the implementation schedule and budget are planned, and the initial indicators are measured with the help of the data history of the company under study. Finally, the implementation program is drafted, which consists of a list of activities to be performed by each operator and which machinery will be used by each one of them.

In the to do phase, the operators are trained according to the needs of the device, for which it is necessary to fill out a training report for this activity. Then, the application program of the artifact to be implemented is applied so that they can learn and execute it.

In the verify phase, we follow up on how the operators manage to execute the program, a report of results is made to a higher level to decide with the work team if the desired results were obtained, if not, we return to the plan phase to make adjustments to the application program, and if the desired results were achieved, we proceed to the next phase, it should be noted that the results must be evidenced in a report made by the person in charge of the process.

Finally, in the acting phase, the application program is standardized so that it becomes a basic procedure of the application company.

E. Model´s indicators

Throughout the management of the implementation of the model, 4 main indicators will be used, aligned to the initially proposed objectives. To measure the achievement generated by the application of the proposed model, the indicators OEE, availability, performance and configuration times will be used. OEE should be less than 85% [10], availability should be at least 90% and performance 95% [29], and configuration times should be a maximum of 10 minutes [20].

TABLE I
TO BE INDICATORS

Indicator	Unit	To Be	Objective
OEE	Percentage	85.00%	Maximize
Availability	Percentage	90.00%	Maximize
Performance	Percentage	95.00%	Maximize
Set-up time	Minutes	10.00	Minimize

Table 1 sets out the indicators, the unit of measurement for each indicator, the objective and the expected standard. For the case of OEE calculation will be considered (1).

$$OEE = Availability \times Performance \times \ Quality \quad (1)$$

Where the also main indicator availability is calculated as in (2), performance as in (4) and quality as in (5).

$$Availability = \ (OT)/(PT) \quad (2)$$

$$OT = PT - FT - ST \quad (3)$$

Where PT indicates the planned time according to work schedule of the company, OT indicates operative time calculated as in (3), FT indicates failure time and ST indicates setup time being all these measures in hours.

$$Performance = PP/(ICP \times OT). \quad (4)$$

Where PP represents the quantity in tons of processed product and ICP means ideal cycle production in tons per hour.

$$Quality = (PP - LP - RP)/PP \quad (5)$$

Where LP means lost production by evaporation and relocating and RP means reprocessed production. Then configuration times are measured directly by chronometer applying (6) for obtain a standardized time for each activity whose sum is the indicator of set-up.

$$Activity\ time = \ OAMT \times (1 + R) \times (1 + S) \quad (6)$$

Where OAMT means observed activity mean time, R represents the Westinghouse rating base on 4 criteria (Skill, effort, conditions and consistency) and S indicates the supplementary percentage by fatigue. Finally, these indicators will show the degree in which the proposed model works.

IV. VALIDATION

The validation will explore which method is adequate to determine if the proposed tools are functional for the improvement of OEE, as well as describe the initial values, how the simulations were performed and how the indicators resulted after the simulation compared to the initial ones.

A. Test scenario

The validation will be performed by means of a simulation since it is a good method for validations that simulate OEE in production lines and its components such as availability, performance, and quality [30]. In the case of the present research work, it will be simulated on the availability and performance sub-items, that is, the MTTR, the set-up time and the minor downtime. Six test scenarios were carried out. Divided into 3 As Is and 3 To Be scenarios with each tool having its scenario in the 2 perspectives. Thus, the following scenarios are formed: Maintenance As Is and Maintenance To Be where the TPM methodology is tested, Set-up As Is and Set-up To Be where the use of the SMED tool is tested and Minor Stoppage As Is and Minor Stoppage To Be where the study of methods is tested.

The 3 parameters are thus tested to adjust the calculation of availability and performance to subsequently calculate the OEE. Likewise, the Arenas software will be used to represent the proposed scenarios and the Input Analyzer will be used to analyze the input data, which is a software derived from Arena.

B. Initial diagnosis

To determine the initial values of the simulations, the times of both the equipment configuration process and the minor stoppages due to trips to the warehouse were measured. On the other hand, for the initial diagnosis of maintenance times, we relied on data from the maintenance logs. Currently, the mechanism for dealing with a machine failure is composed of marked moments: Record the time of the failure in the maintenance log and alert the maintenance area of the failure, wait for the arrival of the maintenance technician and note the time of his arrival, subsequently empty the machine (Whose time is measured by the hourmeter) and proceed to repair the machine per se and record the time of departure of the technician. Finally, the machine is refilled (whose time is measured by the hour meter) and the time of return to operation is recorded in the logbook. For technician waiting time, the difference between the time the failure was recorded and the time the maintenance technician arrived at the machine was found, both times recorded in the maintenance log of each machine, the machine emptying and filling times were obtained directly from the hour meter and the machine repair time was calculated by the difference between the technician arrival time and his departure time after subtracting the machine emptying time, obtaining an MTTR of. 7.14 hours.

TABLE II
AUTONOMOUS MAINTENANCE TIMES

Code	Distribution	Value p (χ^2)	Value p (K-S)	MSE
MA1	UNIF(190, 198)	0.172	> 0.15	0.011800
MA2	NORM(42, 2.22)	0.479	> 0.15	0.005865
MA3	130 + ERLA(6.19, 3)	0.344	> 0.15	0.006199
MA4	NORM(43.2, 1.53)	0.108	> 0.15	0.011036

The minor stoppage to the warehouse is performed in 7 activities: going to the warehouse, searching for the tool, lowering the tool, searching for the warehouse register, filling the register, placing it in its place and returning with the tool to the workstation where the 7 times were considered individually and then added together to obtain the current minor stoppage time, i.e., 6.77 minutes.

TABLE III
MINOR STOPPAGE TIMES

Code	Distribution	Value p (χ^2)	Value p (K-S)	MSE
AL1	UNIF(94, 98)	> 0.75	> 0.15	0.003956
AL2	TRIA(50, 56, 58)	0.0293	> 0.15	0.010933
AL3	NORM(68.9, 3.18)	0.631	> 0.15	0.003407
AL4	UNIF(32, 36)	> 0.75	> 0.15	0.005200
AL5	UNIF(20, 30)	> 0.75	> 0.15	0.008200
AL6	NORM(36.4, 2.22)	0.385	> 0.15	0.004029
AL7	UNIF(89, 93)	> 0.75	> 0.15	0.003400

Currently the set-up is done by means of 15 tasks each time a shift is started to initialize the machine where the 15 times were considered individually and then once added up, the current set up time was obtained, i.e., 20.83 minutes.

TABLE IV
SET-UP TIMES

Code	Distribution	Value p (χ^2)	Value p (K-S)	MSE
SU1	UNIF(68, 73)	0.567	> 0.15	0.005400
SU2	NORM(50.4, 1.24)	> 0.75	> 0.15	0.007024
SU3	UNIF(41, 49)	> 0.75	> 0.15	0.006200
SU4	TRIA(28, 33.5, 38)	0.455	> 0.15	0.004703
SU5	UNIF(63, 68)	0.214	> 0.15	0.012000
SU6	NORM(118, 2.48)	0.295	> 0.15	0.004610
SU7	NORM(47.3, 2.5)	0.419	> 0.15	0.006474
SU8	114 + ERLA(0.632, 5)	0.205	> 0.15	0.006768
SU9	UNIF(47, 52)	> 0.75	> 0.15	0.006800
SU10	UNIF(104, 113)	0.543	> 0.15	0.007400
SU11	UNIF(127, 131)	> 0.75	> 0.15	0.003600
SU12	NORM(182, 5.3)	0.231	> 0.15	0.006631
SU13	TRIA(98, 101, 102)	0.553	> 0.15	0.005906
SU14	UNIF(68, 73)	0.523	> 0.15	0.006800
SU15	NORM(62.8, 2.54)	0.242	> 0.15	0.007310

With the 3 parameters obtained, a current availability of 88.05%, an efficiency of 85.06% and an OEE of 73.27% were calculated.

C. *Commissioning*

First, the As Is values were simulated and the number of replicates was calculated under the empirical formula based on the average and the average interval width as in (7) [31] where NO indicates the optimum number of replicates, NI is the initial number of replicates that is usually 30, H indicates the half-interval, C indicates the confidence percentage that in this case is 10% and X means the mean of the set of replications.

$$NO = NI \times (H/(C * X))^2 \quad (7)$$

In the case of As Is maintenance times, 30 sample runs were performed and the optimal number of samples for the average was calculated using confidence interval’s formula [31] knowing that the average MTTR is 7.1317 hours, and the average width of the interval is 0.0141 hours. Finally, it was obtained that the number of replicates needed is 1 which is less than 30 therefore the result is accepted. In addition, the validity of the simulated system is also checked since the actual MTTR is 7.14 hours which is within the interval [7. 1317-0.0141; 7. 1317+0.0141].

Then in the case of the set-up times As Is 30 sample runs were performed, we proceeded to calculate the optimal number of samples for the mean considering the formula of confidence interval [31] knowing that the average set-up time is 20.8271 minutes, and the average width of the interval is 0.0071 minutes. Finally, it was obtained that the number of replicates needed is 1 which is less than 30 therefore the result is accepted. In addition, the validity of the simulated system is also checked since the actual set-up time is 20.83 hours which is within the interval [20.8271-0.0071; 20. 8271+0.0071].

Finally, in the case of the minor stoppage time, 30 sample runs were performed and the optimal number of samples for the mean was calculated using confidence interval’s formula [31], knowing that the average minor stoppage time per trip to the warehouse is 6.7666 minutes and the average width of the interval is 0.0047 minutes. Finally, it was obtained that the number of replications needed is 1 which is less than 30 therefore the result is accepted. In addition, the validity of the simulated system is also tested since the lowest downtime per run to the actual warehouse is 6.77 hours which is within the interval [6.7666-0.0047; 6.7666+0.0047].

Thus, it was proved that the As Is simulations match reality and, therefore, the To Be simulations were performed with the following considerations with respect to the As Is based on the proposed model.

Regarding maintenance mechanics, 81% of machinery failures are one of the 6 basic activities [16], which means that if autonomous maintenance were performed in 81% of the cases, it would not be necessary to wait for the arrival of the technician to repair the failure.

In the proposed set-up times, the activities that do not add value were eliminated, thus removing the activities of rinsing, detergent preparation, detergent concentration test, product hose assembly, water test and shirt inspection. Likewise, the activities of avocado height adjustment, bearing adjustment, and jersey assembly can be carried out once the machine has been started up, therefore, they are no longer considered lost time in set-up. Therefore, the only activities that would add up against equipment availability would be recirculation, nozzle disassembly, drag paddle change, intermediate paddle change and line start-up. Finally, regarding the downtime due to the warehouse, it was proposed to organize the warehouse in order to reduce the tool search time; it was proposed to fix the register to eliminate the time to search for the register and put it in place. Then, once the differences between the As Is and To Be simulations were known, we proceeded to the To Be simulations.

In the case of the maintenance times To Be 30 sample runs were performed, the optimal number of samples for the mean was calculated using confidence interval’s formula [31] knowing that the average MTTR is 4.4973 hours, and the mean width of the interval is 0.0696 hours. Finally, it was obtained that the number of replicates needed is 1 which is less than 30 therefore the result is accepted. Then the proposed simulated value of MTTR is in the interval [4.4973-0.0696; 4.4973+0.0696].

In the case of the set-up times To Be 30 sample runs were performed we proceeded to calculate the optimal number of samples for averaging considering the formula of confidence interval [31] knowing that the average set-up time is 7.3331 minutes, and the average width of the interval is 0.0032 minutes. Finally, it was obtained that the number of replicates needed is 1 which is less than 30 therefore the result is accepted. Then the proposed simulated value of the set-up time is in the interval [7.3331-0.0032; 7.3331+0.0032].

Lastly, in the case of the minor downtime To Be 30 sample runs were performed, the optimal number of samples for the mean was calculated using confidence interval's formula [31] knowing that the average minor downtime per trip to the warehouse is 4.6836 minutes and the average width of the interval is 0.0044 minutes. Finally, it was obtained that the number of replications required is 1 which is less than 30 therefore the result is accepted. Then, the proposed simulated value of the lowest stopping time per trip to the warehouse is in the interval [4.6836-0.0044; 4.6836+0.0044].

Finally, to verify that the proposed improvements have an impact on the real production of the company beyond the indirect production times such as the repair time, the set-up time and the time of minor stoppages, the production line was simulated. ACP production in Arenas software. As well as ensuring that improvement will not be hampered by bottlenecks or other production constraints. Then, the simulation of the TO BE system was carried out based on the improvements achieved in the previous 3 simulations.

Then, 30 sample runs were made and the optimal number of samples for the mean was calculated using confidence interval's formula [31] knowing that the average production is 10355 tons and the mean width of the interval is 4.2462 tons. Finally, it was obtained that the number of necessary replicas is 1, which is less than 30, therefore the result is accepted. Then the proposed simulated value of the shortest stop time per trip to the warehouse is in the interval [10355-4.2462; 10355+4.2462]. This indicates an improvement of the real productive capacity in 5.34% once the improvement is applied. This concludes the test scenario simulations and proceeds to the analysis of the To Be results in the next section.

D. Validation´s indicators

Once the relevant simulations have been carried out to evaluate the scope achieved by the proposed model in the three simulated parameters: the MTTR, the set-up time and the minor stoppage time. Subsequently, the indicators are calculated from the simulated parameters. In this way, a new availability of 91.01% is obtained, a yield of 97.65% and considering that the quality remains the same at 99.30% since no change was made that affects it. Then the problem indicator would be an OEE of 88.24%. The results were evaluated based on the standards set forth by previous authors, and the standards set forth in the World-Class indicators for OEE were exceeded, i.e., availability greater than 90%, performance greater than 95% and OEE greater than 85%. On the other hand, the configuration time was reduced to 7.33 minutes.

TABLE V
INDICATORS TO BE VS SIMULATION

Indicator	Unit	To Be	Simulation
OEE	Percentage	85.00%	88.24%
Availability	Percentage	90.00%	91.01%
Performance	Percentage	95.00%	97.65%
Set-up time	Minutes	10.00	7.33

V. CONCLUSIONS

The TPM is the engineering methodology that is best suited to remedy the problem of low equipment efficiency, which is caused by machinery failures, the SMED for set-up times and the study of methods to the times of minor stoppages, having as a limitation the redistribution of the plant. Then, through the application of TPM through an autonomous maintenance program so that the same operators of each machine can deal with the basic maintenance that arise, it was possible that the time of failures in machinery was reduced from 12.09 hours to 4.50 hours, obtaining a reduction of 62.78%.

A second point to conclude is that through the application of SMED through the proposal of the new machinery configuration plan, the machinery configuration time was reduced from 20.83 minutes to 7.33 minutes, obtaining a reduction of 64.81%.

Finally, through the application of a study of methods through a new definition and minor stoppage procedure, it was possible to reduce the minor stoppage time from 6.77 minutes to 4.68 minutes, obtaining a reduction of 30.87%.

In addition to the 3 measurable results previously mentioned, other non-quantitative results were also achieved. It was possible to improve the level of the company's maintenance culture through training and involvement of new methodologies not previously used, leaving the possibility of continuing to improve the organizational maintenance climate involving other pillars of the TPM.

Another conclusive achievement was the improvement of staff involvement for the organization and their sense of belonging as a side effect of the autonomous maintenance application as it has referred in literature review of TPM. Carrying out long-term autonomous maintenance activities reduces the investments previously directed to the machines, because this increases the useful life of the equipment through the truthful supervision of the operators.

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