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Successful implementation of the SMED and TPM tools under the PDCA methodology to increase order fulfillment in a company in the Plastic Sector

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Abstract*– According to the INEI, the companies producing plastics in Peru have increased by 27.65% in the period from 2015 to 2020 in the city of Lima-Peru, being the most representative both in number of companies and in their annual sales, which are 352,514 soles on average. Likewise, it is important to emphasize the millions of soles that companies invest in importing machinery to be able to work the plastic product, however, statistics presented in this source (INEI, 2021) mention that only 11% of companies use the total of installed capacity, which is a significant figure that must be taken into consideration. For this reason, this article will thoroughly address the problems caused by delays when delivering orders in a company in the plastic sector. The company under study has a low order fulfillment rate of 57.38%, which represents 11% of the company's total costs. To improve this ratio, the Total Productive Maintenance (TPM) tools and its preventive and autonomous maintenance pillars will be used, as well as the use of the Single Minute Exchange of Die (SMED) tool to reduce delays in the production process. The implementation of the tools lasted 18 weeks at a cost of S/ 30,216. Finally, the result of the implementation of TPM and SMED was positive since it was possible to improve the downtime of the machines by 70% and increase productivity by 42%.

Keywords*-- Maintenance, OTIF, TPM, SMED, Order Fulfillment, Injection Process, Blow Process, Preventive Maintenance, Autonomous Maintenance.

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I. *INTRODUCTION*

The Deming Cycle methodology is used to implement continuous improvement and solve problems in a structured way in four steps. This process is implemented by applying tools that improve those that present deficiencies. The company under study presents problems with the On time In Full (OTIF) indicator, which measures the number of orders delivered on time and with the correct quantity with a technical gap of 18.29% with respect to the sector. In addition, this generates an economic impact of 11% with respect to total income. According to the INEI [1], it reports that only 11% of the organizations that produce plastic containers use 100% of their installed capacity. Also, according to [2], there is currently a shortage of raw material, which will influence the increase in costs. Likewise, they commented that during the next few years the workforce in this sector will be reduced by 40%, further delaying the production process of the plastic sector. For this reason, it is of great importance to solve the difficulties that these producing companies present in their production process.

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According to the sector, according to the ITP [3], Peru is in second place with the highest production volume in Latin America after Colombia. [3]. This is due to the lack of maintenance performed on the machinery. For this reason, the importance of solving the problem of delays in the delivery of orders that this company presents mainly arises. This originates from the lack of availability of machinery; This causes penalties and reprocessing in the production process. In this context, Buitron [4], applied the PDCA methodology to increase the efficiency of companies in the plastic sector where he mentions that he managed to solve the problem of the company, implementing the TPM and 5S tools. Its solution was validated through the use of the OEE indicator, with which it was able to serve a greater number of orders.

The PDCA methodology has been implemented in various companies, which are mainly focused on improving the quality of processes. In order to develop the improvement of these processes, the TPM and SMED tools will be applied. According to [5] the TPM tool focuses on the review The Deming Cycle methodology is commonly used to implement continuous improvement and solve problems in a structured way in four steps. This is implemented by applying tools that improve those processes that present deficiencies. The company under study presents problems with the OTIF indicator, which measures the number of orders delivered on time and with the correct quantity with a technical gap of 18.29% with respect to the sector. In addition, this generates an economic impact of 11% with respect to total income. According to the INEI [1], it reports that only 11% of the organizations that produce plastic containers use 100% of their installed capacity. Also, according to [2], there is currently a shortage of raw material, which will influence the increase in costs. Likewise, they commented that during the next few years the workforce in this sector will be reduced by 40%, further delaying the production process of the plastic sector. For this reason, it is of great importance to solve the difficulties that present an integral part of all the operations related to the maintenance of the equipment. In addition, it presents 8 pillars that solve different problems in the maintenance area. According to [6] in his article "Implementing Total Productive Maintenance in a Manufacturing Small or Medium Sized.

Enterprise", implemented the TPM tool to reduce the company's untimely stops, analyzing the machines that allowed it to develop maintenance procedures, thereby increasing their efficiency and availability by 60%. They also obtained benefits regarding the performance of the company and the delivery of orders. On the other hand, [7] applied the SMED tool in his research entitled.

"Smed Application to reduce set up time on a plastic injection machine", which seeks to reduce the high setup times in the company's machines. In the same way, through the analysis of the company's activities, it manages to reduce these times by 70%. In this sense, the objective of this study is to design a maintenance plan that allows minimizing delays when delivering orders, to increase efficiency in production lines, thus also improving quality, as well as a plan to reduce setup times through correctly detailed and explained procedures.

The motivation of this research is to improve the processes of organizations and encourage the use of engineering tools, through the demonstration of positive results, which will benefit the delivery of orders on time. Likewise, to value the human capital that is essential to have them satisfied as well as the clients, since they are the ones who carry out the activities and it is essential to have their commitment to achieve improvements in the processes and to be able to verify the correct use of the tools with those indicators.

This article is organized as follows. In section II where the State of the Art is found. Section III describes the methodology to be used. In section IV, the results are shown and in section V the discussion about the results and conclusions is presented.

II. STATE OF THE ART

Poor planning and repair of the machines, together with times that are not productive are the causes of delays in the production process and, consequently, delays in the delivery of orders. Therefore, different authors searched for different tools to provide a solution to this problem.

A. *Maintenance of machines applying TPM.*

This typology seeks to increase the availability of machines through the TPM pillars and continuous reviews to increase productivity and minimize delays in processes and deliver an order on time. In 2018, it was sought to reduce the downtime of the machines, which affected the productivity of the company, the results obtained through the application of the TPM managed to increase the availability of the machines by 80%, reducing the time to 120 minutes. of inactivity of the machines [8]. In 2019, they sought to reduce production delays, which affected the company's sales. The results of this were that the OEE of the company's machinery was improved by 13%, thus making the machines work longer without interruptions. Likewise, the improvement in the attention of orders by the company [9]. On the other hand, in the same year, an effort was made to reduce maintenance costs, since these were excessive for the company, since they generated large economic losses due to breach of the contract in complying with the agreed delivery terms. The results of this were that costs were reduced by 80%, reaching €42,093 and the OEE of the machines increased by 77% [10].

B. Reduction of set up times applying SMED.

This typology focuses on improving processes through the elimination of unnecessary activities at change times, since it is common that the activities carried out by the operators, several of these, do not add up. value at setup times. In 2019, [11] sought to reduce the high setup times, which represented 40% of the scheduled hours. To solve this, he applied the tools of SMED, 5S and TPM, with which he managed to increase the availability of the machines by 7% and managed to reduce preparation times by 36.79% [12]. On the other hand, in 2020 [13], it sought to reduce times during the mold change process, which affected the company by 30%. To do this, the SMED tool was applied, managing to reduce times by 70% since it classified the activities that did not add value to the process. In addition, in 2022 [14], it sought to reduce setup times, which directly affected compliance with the date established in the contract due to a very deficient production line. Through the application of the SMED tool under the Lean Manufacturing methodology, it managed to reduce setup times by 8.6%. In addition, it managed to improve order delivery times by 24%.

C. *Quality systems in the production process:*

The purpose of this typology is to reduce defective products through the correct configuration of the parameters, which are responsible for the material being molded in the final container. In 2021 [15], it sought to reduce the defective products that were generated in the injection process. To solve this, he applied the tools of Six Sigma and DMAIC, with which he sought to carry out the analysis of the 5 whys, with which he identified the problems that occurred. From this research, it reduced defects by 12.56%, managing to reduce costs by 38.3%. On the other hand, [16], I seek to solve defective products by obtaining the optimal parameters for the machine to work efficiently. For this, he applied an artificial neural network and the Taguchi tool, with which he obtained that the correct parameters are at a temperature of 230°C, a filling time of 1s, cooling of 1s and a pressure of 120 Pa; With these, he managed to reduce defective products by 32%.

D. Product dispatch management systems:

This typology seeks to improve the dispatch process, making it more efficient when dispatching orders or registering new incoming products. In 2018, [17], they sought to improve the dispatch as they found that there was poor product management. For this, he applied the Six Sigma tool with which he tried to improve and correctly organize the warehouse to improve dispatch management. The results obtained from this were that dispatch times were reduced by 12 hours and the delivery quantity of orders was improved by 98.76%. On the other hand, in 2020 [18], he sought to optimize the organization of the warehouse. For this, it applied the ICA (Integrated Cluster Allocation) tool, with which it sought to improve the number of on-time deliveries of its orders.

III. RESEARCH INPUT

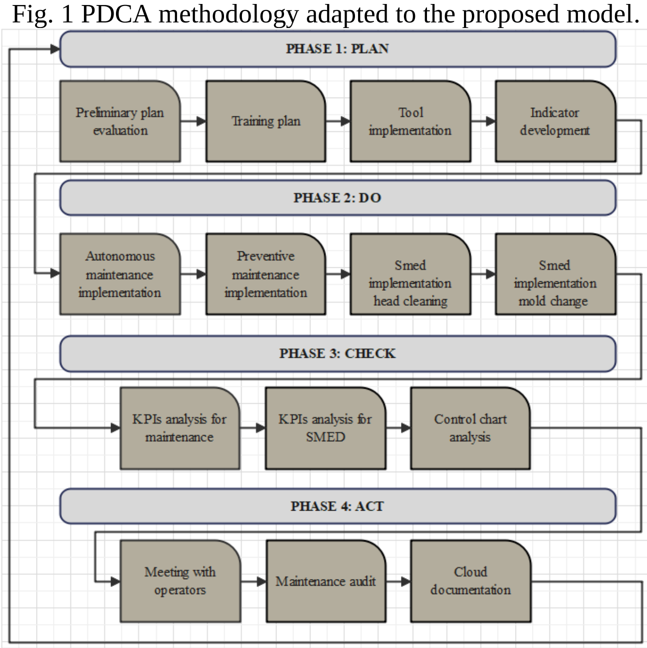
A. PROPOSED MODEL

In the investigation, various scientific articles were compiled that addressed the tools of TPM, SMED and the PDCA methodology focused on the problem of the high rate of delays in the fulfillment of orders in a company in the plastic sector. These articles were analyzed to know the structures, limitations and above all the results that were achieved with the implementation to take them into consideration in the development. Therefore, the contribution of this proposed model is that it is sustainable over time and adaptable with any tool to achieve the objective of the PDCA, which is continuous improvement and achieve the expected objectives with the implementation. As shown in Fig. 1, the following model based on the PDCA methodology is proposed.

B. PROPOSED PROCESS FOR THE MODEL

As shown in Fig. 1, to correctly implement the TPM and SMED tools, we used the PDCA methodology with which the continuous improvement of the implementation was sought.

Fig. 1 PDCA methodology adapted to the proposed model.



- **Phase 1: Plan**

n the planning phase, the preliminary evaluation of the plant will mainly be carried out, analyzing each activity and area of the plant in search of the most common problems. Likewise, within this phase a training plan will be developed with the topics to be discussed so that the operators know about the tools to be implemented. Also, the schedule will be developed on the activities to be carried out during the implementation and the development of indicators to measure the improvements made.

- **Phase 2: Do**

In the phase of doing, we will seek to implement the TPM and SMED tools. In the first place, the implementation of the TPM will consist of the pillars of autonomous and preventive, in which the training of the TPM will be sought and an instruction on how to carry out revisions to the machines will be prepared. In the preventive pillar, the maintenance plan was carried out for the injection and blow-moulding machines, which present low availability and efficiency. Secondly, for the SMED tool, the DAP of the most critical processes will be developed and analyzed in search of activities that add value or not to the process.

- **Phase 3: Check**

In the verification phase, the evaluation of the KPIs and process control charts will be mainly developed with the aim of verifying if the process is being applied correctly and if the improvement is effective.

- **Phase 4: Act**

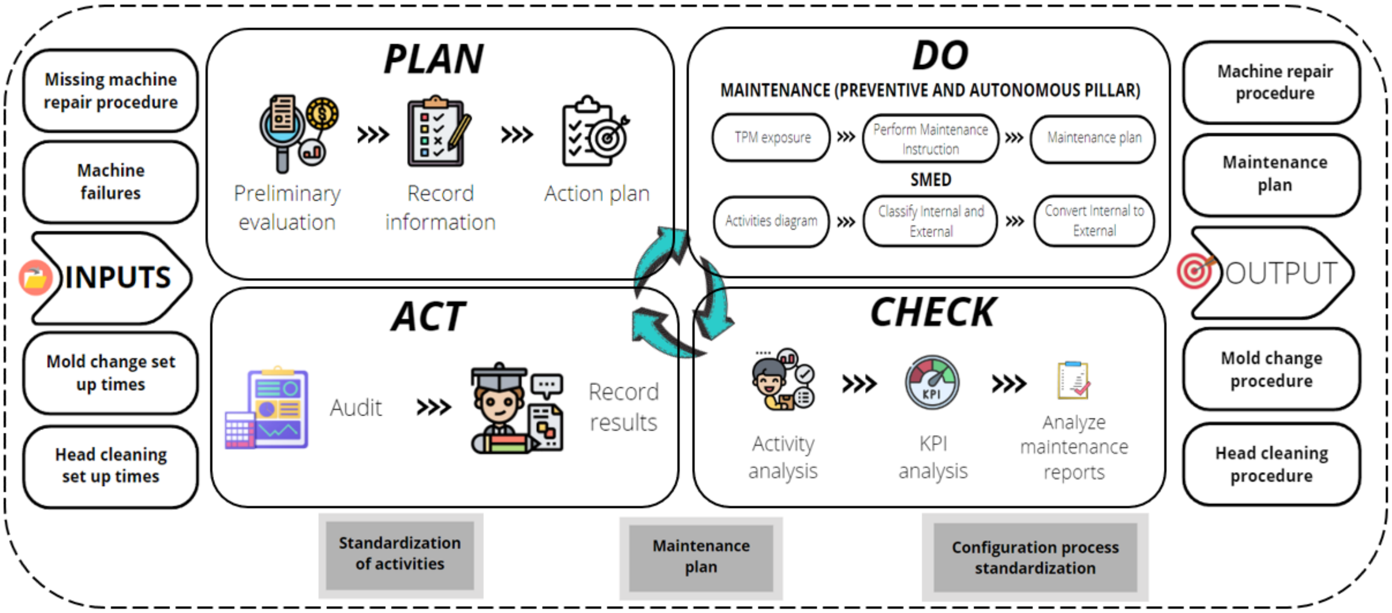
Finally, in the act phase, which has continuous improvement as its main objective, continuous meetings will be held in which it will mainly seek to resolve those concerns that the staff have and that may be harming their development with the new tools. A maintenance audit will also be sought to verify if it was successfully implemented and if the workers have correctly understood the TPM tool. Finally, the information collected will be documented in the cloud to continue with continuous improvement.

C. LIMITATIONS

The limitations of the implementation of the model correspond to the difficulty of some of the tools and resources proposed by the company, for which the following points were identified as limitations:

- It will only be applied to the processes of changing the head and cleaning the machine. Which represent the largest amount of busy time.
- Only two pillars of the TPM will be used, the autonomous and the preventive since they are the most important and require less time and resources for their full implementation.
- Only the training of the TPM and SMED tools will be carried out for the operators of the same area, that is, maintenance and plant.

Fig 2 Proposed Model



D. MODEL INDICATORS

The indicators for the measurement of the model will be the following, as in (1) and (2):

- On Time in Full (OTIF)

$$\text{On Time} = \frac{\text{N° de entregas a tiempo}}{\text{N° total de entregas}} \quad (1)$$

$$\text{In Full} = \frac{\text{N° de entregas completas}}{\text{N° total de entregas}} \quad (2)$$

- Overall Equipment Efficiency (OEE), as in (3)

$$\text{OEE} = \mathit{Disponibilidad} \times \mathit{Rendimiento} \times \mathit{Calidad} \quad (3)$$

- Medium time between failures (MTBF), as in (4)

$$\text{MTBF} = \frac{\text{Tiempo total de trabajo} - \text{Tiempo de averia}}{\text{Número de fallas}} \quad (4)$$

- Medium time between repairs (MTTR), as in (5)

$$\text{MTTR} = \frac{\text{Tiempo total de mantenimiento}}{\text{Número de reparaciones}} \quad (5)$$

V. VALIDATION

This section analyzes the inefficiency that occurs in the production process of the company dedicated to the production of plastic containers. In order to validate the implementation of the tools in the company, a pilot model was carried out, which allowed to verify in the short term, the performance of the proposal made.

Study area:

In the company it was possible to demonstrate high set up times due to the lack of standardized processes. In addition, there is evidence of a lack of availability and performance of the machinery due to the lack of a maintenance plan and standardized processes. These problems generate delays to deliver orders on time, since the quantity is not available now, delivering incomplete or out-of-date orders.

These problems are evidenced in the following indicators (see Table I):

Table 1 Table of Indicators

INDICATOR	AS IS	TO BE
OTIF	57.38%	90%
MTTR	1.06 h	4 h
MTBF	1.26 min	30 min
OEE	70.50%	90%
SET UP TIME - MOLD CHANGING PROCESS	140.0 min	60 min
SET UP TIME - HEAD CLEANING PROCESS	207 min	100 min

Implementation of the TPM and SMED tools:

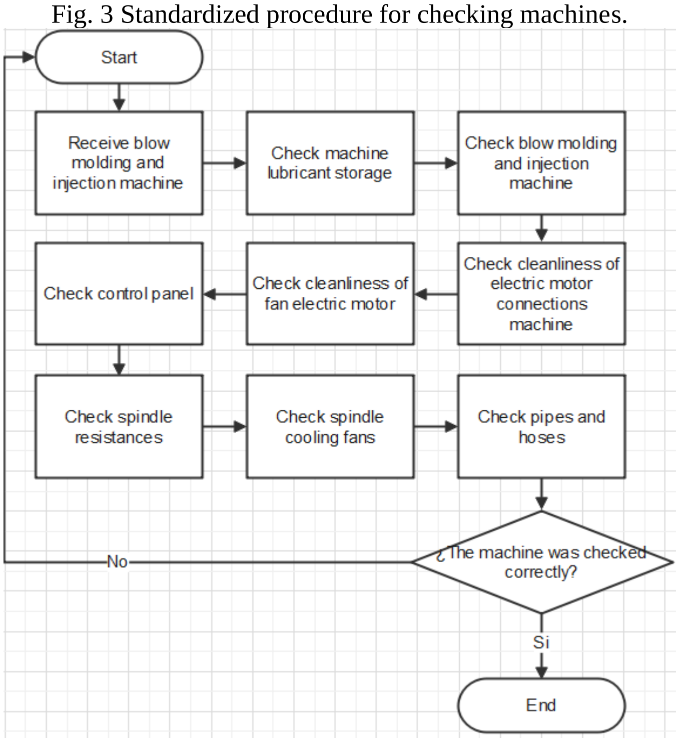
To correctly implement the tools, different methods were carried out. In the first place, for the implementation of the TPM tool, a maintenance plan was proposed, which allows employees to know the scheduled dates to carry out a technical review of the machine and improve its availability and performance (see Table 2):

Table 2. Maintenance Plan

MACHINE / TIME	CODE	FRECUENCY	2022															
			OCTOBER						NOVEMBER					DICEMBER				
			SEM 39	SEM 40	SEM 41	SEM 42	SEM 43	SEM 44	SEM 44	SEM 45	SEM 46	SEM 47	SEM 48	SEM 48	SEM 49	SEM 50	SEM 51	SEM 52
EXTRUDER BLOWER	ES 02 (K-02)	MONTHLY																
	ES 04 (K-04)	MONTHLY				21					18					16		
	ES 06 (J-05)	MONTHLY				17					17					17		
	ES 07 (J-06)	MONTHLY			13		26			12		26				13		26
	ES 08 (J-07)	MONTHLY			12		25			11		25			10		23	
	ES 09 (J-08)	MONTHLY			11		24			10					9		22	
	ES 10 (Uniloy)	MONTHLY		7						7					7			
	ES 11 (PV-01)	MONTHLY				22						21					21	
	ES 12 (PV-02)	MONTHLY																
	ES 13 (PV-03)	MONTHLY			15						14					12		
	ES 14 (JH-01)	MONTHLY				19					15					14		
	ES 15 (JH-02)	MONTHLY				20					16					15		
	ES 16 (JH-03)	MONTHLY				22						22					20	
	ES 17 (JH-04)	MONTHLY					27					23					19	
	ES-18 (STX)	MONTHLY					28						28					28
	ES-19 (JH-05)	MONTHLY					29						29					29
	ES-20(PARKER)	MONTHLY						31					30					30
	ES-21(PLASTB)	MONTHLY			16					13					11			
INJECTOR	IN 02	BIMONTHLY	3											2				
	IN 05	BIMONTHLY	4												5			
	IN 08	BIMONTHLY	5												6			
	IN 09	BIMONTHLY																
	IN 11	BIMONTHLY	8												8			
	IN 12	BIMONTHLY		4												5		
	IN 13	BIMONTHLY		5												6		
	IN 14	BIMONTHLY		6												7		

Likewise, as shown in Fig. 3, in order to ensure that the machines are being serviced correctly, a standardized procedure was developed for the service of machines in conjunction with maintenance personnel, since they are experienced in this field.

Fig. 3 Standardized procedure for checking machines.



On the other hand, to correctly implement the SMED tool, the analysis of the activities was carried out, as well as their classification, with the aim of having a standardized process. (see Tables III and IV):

Table 3 Head Cleaning Process Standardization

NEW SEQUENCE OF ACTIVITIES OF THE HEAD CLEANING PROCESS		Page : 1/2 Code : IN - 08 Date : 02/08/22		
Produced by: Jhon Salvador y Diego Mujica		Machine Blower		
Approved by : Jefe de producción		Date : 02/08/22		
N°	Actividades	Time	Internal	External
1	Move tools to the cleaning area	4.51		x
2	Clean workstation	9.75		x
3	Lubricate head parts	3.30		x
4	Loosen the head bolts	4.37		x
5	Remove header connection	1.09		x
6	Check screw misalignment	3.34		x
7	Head off	8.47	x	
8	Disarm the head	4.28	x	
9	Clean the inside of the head	3.84	x	
10	Pure liquid rinse	4.00	x	
11	Dry head	3.01	x	
12	Arm head	7.15	x	
13	Check head assembly	4.51		x
14	Mounting head	8.58		x
15	Adjust cap screws	4.84		x
16	Place header connections	3.17		x
17	Check head connections	2.60		x
18	Configure the machine	7.80		x
19	Check the operation of the machine	4.18		x
	TOTAL (min)	92.79	30.75	62.04

Table 4 Mold Change Process Standardization

NEW SEQUENCE OF THE MOLD CHANGE PROCESS		Pag : 1/2 Códe IN-08 Date: 02/08/22		
Produced by : Jhon Salvador y Diego Mujica		Machine : Injector		
Approved by: Production Manager		Date: 02/08/22		
N°	Actividades	Time	Internal	External
1	Verify disassembly of mold	6.14		x
2	Bring tools to change area	5.00		x
3	Remove mold connections, electrical, pneumatic and hydraulic part.	3.54	x	
4	Close machine protection door	1.57		x
5	Open machine protection door.	1.02		x
6	Hook crane on the mold.	1.74		x
7	Close machine protection door	1.01		x
8	Loosen set screws of the fixed and mobile plate of the mold	2.00	x	
9	Close the protection door of the machine	1.00		x
10	configure dashboard	3.27		x
11	check disassembly	1.54		x
12	Pull the hoist slowly to remove the mold	12.00	x	
13	Slowly lower the mold onto the table	2.09	x	
14	Disengage the hoist from the mold	1.51	x	
15	Attach to the mold to assemble	1.22	x	
16	Pull and lift the mold with the crane	5.00	x	
17	Release slowly and lower the mold to the height of the machine	2.56	x	
18	Adjust the fixing screws of the fixed and mobile mold plate.	6.00	x	
19	Disengage the hoist from the mold	1.88		x
20	Place refrigeration and other connections	3.00		x
21	Check the operation of the mold	5.42		x
	TOTAL (min)	68.51	35.92	32.59

Measurement and analysis of indicators:

To measure the objectives achieved, a general review was carried out comparing the initial values with those after the implementation. The results obtained are shown below. (see Table V).

Table 5 Final Table of Indicators

INDICATOR	AS IS	TO BE
OTIF	57.38%	76%
MTTR	1.06 h	0.5 h
MTBF	1.26 min	4.26 h
OEE	70.50%	91.33%
SET UP TIME - MOLD CHANGING PROCESS	140.0 min	55.38 min
SET UP TIME - HEAD CLEANING PROCESS	207 min	92.79 min

VI. CONCLUSIONS

The implementation of the proposal using the PDCA methodology using the TPM and SMED tools through a pilot validation, resulted in significant improvements for the reduction of customer complaints of 85%. Likewise, it was possible to reduce the number of defective products thanks to the implementation of the TPM, which allowed the best performance of the machinery by 76%. On the other hand, it was possible to increase the time between machine failures to 4.26 hours, representing greater productivity for the company, being able to serve a greater number of orders per day. On the other hand, it was possible to reduce the preparation times of the machines to 55.38 minutes and 92.79 minutes for the mold change and head cleaning correspondingly. This means that the availability of the machine after each batch will be faster.

The implementation of this project in the study company, through an economic analysis, it was verified that it obtained a NPV of S/. 40,927.80 and with an IRR of 59.41%, which indicates that the project is viable and acceptable.

Finally, it was determined that this research provides a new research model through the implementation of Industrial Engineering tools and the PDCA methodology to increase the OTIF indicator.

RECOGNITION

To the Research Directorate of the Peruvian University of Applied Sciences for the nuptial support to carry out this research work through the UPC-EXPOST-2023-1 incentive.

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