Model based on TPM and Standardization for the maximization of efficiency in an SME in the plastics sector

Jhonatan Aguilar-Schlaefli, B.Eng.[1], Zuyeiry Campos-Campos, B.Eng.[2], Claudia Leon-Chavarri, M.Eng.[3], and Martin Saenz-Moron, M.Sc.[4]
[1234]*Industrial Engineering Program, Peruvian University of Applied Sciences*, Lima, Peru,
[1]u201815441@upc.edu.pe, [2]u201818586@upc.edu.pe, [3]pcincleo@upc.edu.pe, [4]pcinmsae@upc.edu.pe

Abstract-The plastics industry is important in the world due to its recurrent use in daily life and the supply it provides to other sectors such as medicine, transportation, health. Previous studies show that the average difference in global efficiency between the manufacturing industry and the World Class ranges between 15 to 25 percentage points, also affecting the plastics sector. The case study presents a gap of 17% regarding this metric in the thermoforming line. This efficiency gap has had an impact on cancelled orders, which generate 18.8% of annual sales losses. During the analysis it was determined that availability losses are generated by constant machinery breakdowns and quality losses are caused by the high rate of nonconforming products. Thus, in view of the scarcity of efforts in the sector, an efficiency maximization model is proposed that combines the management of time and machinery with the quality associated with the process. To this end, the integration of tools such as 5S, autonomous and planned maintenance to reduce unscheduled stops and standardization under a continuous improvement framework to reduce the sources of quality loss is proposed. In this way, an improvement of 12.15% in the efficiency of the line is achieved, increasing by 3.36% and 10.96% in the Availability and Quality indicators respectively for the M4 thermoforming machine.

Keywords—TPM, Standardization of Work, Global Efficiency, Plastics Industry

I. INTRODUCTION

According to the Plastics Sector Report, world production of this material has increased steadily, amounting to 348 million tons, of which America has contributed 4% [1]. Peru, on the other hand, has presented an accumulated increase of 11.2% during the period from 2013 to 2018. SMEs predominate in the plastics sector with 94.8%. Nowadays, many of these companies present an increase of waste in their production which causes a low level of efficiency in their processes. Especially for SMEs, implementing methods to solve these barriers has been difficult, due to their limitations [2].

In the plastics industry, the production process requires continuous operation, so a reduction in machine availability means a reduction in the quantity and level of production. Similarly, a reduction in the quality index requires processing more raw material than planned. These types of losses are largely explained in the OEE literature. However, according to the literature research, there is a gap between availability assurance and quality control in an integrated approach to maximizing the efficiency of a production line [3].

It is important to eliminate and control the causes associated with machine downtime by using a simplified TPM pillar model to reduce unproductive times [4]. In the same way, very few research focus this implementation based on the company's resources, so the use of support tools such as 5S is relevant [5]. Likewise, it is important to mitigate the sources of variation in the work performed by the operators. To this end, standardization, under a DMAIC improvement approach, reduces waste and increases process efficiency [6]. The application of Total Productive Maintenance (TPM) as a tool to maximize availability and, consequently, OEE has proven to be successful in all industrial sectors and in SMEs [4], [7], [8]. From a quality standpoint, the DMAIC cycle, in conjunction with standardization, has been used to achieve process capability in similar manufacturing industries that reduce the defect rate to less than 1% [9], [10].

Market competitiveness in the plastics manufacturing industry requires further improvement of the production process. However, SMEs in the sector do not have the knowledge, method, and resources to achieve this. Similarly, there is a gap between maintenance-based and quality-based methods to decrease losses. To increase OEE in an SME, it is not enough to increase machine availability but also end-of-production process compliance. To reduce this gap, it is necessary to design a method that includes both forms of loss reduction and that is affordable for the size of the SMEs. [5], [11].

Finally, this research has the following structure: literature review, presentation of the proposed method, validation of the model in the case study and conclusions.

II. STATE OF THE ART

1. *Overall efficiency in a production line*

The Overall Equipment Effectiveness (OEE) indicator was developed by Nakajima in 1988 to meet the need to determine the efficiency of the machines comprising a production system [3]. The measurement of this indicator allows the identification of the six main sources of loss and their mitigation through the implementation of lean tools [12], [13]. Similarly, Nakajima states that every organization must achieve at least 85% in OEE to belong to the World Class [3], [13]. Muchiri and Pintelon state that the average difference between this world standard and that achieved by manufacturing companies ranges from 15

Digital Object Identifier (DOI):
http://dx.doi.org/10.18687/LEIRD2022.1.1.71
ISBN: 978-628-95207-3-6 ISSN: 2414-6390

to 25 percentage points, which represents a major impact on the competitiveness of the industrial sector [14]. However, despite the usefulness of the indicator and its analysis of losses, the feasibility of its use has been widely questioned over time. This questioning is based on the indicator's effectiveness in measuring a production system beyond an isolated machine, a condition that is impossible to meet [15], [16]. Thus, multiple adaptations have been developed since its inception to achieve the most realistic metric for measuring efficiency over a complete production system [15], [17].

The scientific contribution made by the analysis of production losses and the structuring of an indicator to measure them in a complete way, developed by Nakajima, is indisputable. However, it is evident that, when the analysis of a more complex system is required, the approach presents several inconsistencies [15], [16]. In the same way, analyzing the World Class as an ideal parameter, this will be difficult to achieve if the system is not analyzed due to the interrelation between the variables shared from one process to another [15]. Therefore, for a detailed analysis of the efficiency of a production line considering the relationship between the processes performed by the machines that compose it, the models that are most widely used are Overall Fab Effectiveness (OFE), Overall Line Effectiveness (OLE) and Overall Throughtput Effectiveness (OTE), the latter considering the different types of production lines present in the industry [15].

2. *Basic tools of Lean Manufacturing*

Lean Manufacturing philosophy focuses on improving the performance of the production system by eliminating processes that do not generate value. Therefore, some research affirms that the implementation of this philosophy reduces waste flow and thus reduces costs and improves product quality. Lean practices can be carried out with the support of tools such as 5S, Visual Management, Kanban Kaizen or VSM, which increase the probability of increasing productivity. The 5S allows to set up an area in such a way that facilitates and improves the organization and cleanliness of it. On the other hand, the VSM allows to identify and eliminate the most wasteful processes, the execution of this mapping is essential especially when it comes to detecting the bottleneck of the production flow [18], [19].

The use of these lean manufacturing practices has shown several successes in the manufacturing industry. In an SME in the industrial sector, an average performance index of 97% was achieved. In a packaging area, productivity was increased by 13.6% and material flow distances were reduced by 50%. In a milling process it was possible to increase production by 57.15% and reduce cycle times by 69.64%. And in a company that manufactures valves, productivity increased from 25% to 28% [11], [20]–[22]. In this way, these practices become a key factor for industries to successfully manage their quality, time, and costs of their processes through the application of methods and tools presented by this philosophy [5].

3. *TPM Pillars: Autonomous and Planned Maintenance*

Total Productive Maintenance is a strategy that guarantees the optimal operation of machinery and therefore allows companies to reach the most competitive efficiency standards in the market [3], [23]. In the same way, it allows to extend the useful life of the machine, thus reducing unplanned shutdowns. In this way, several authors assure that the role of maintenance is relevant when seeking to improve production standards such as: equipment availability, quality, and performance. According to several authors, the application of TPM has increased the overall efficiency of equipment in a spinning plant, a forging workshop, a clutch manufacturing company and a plastic bottle producer by 10.93%, 17.08%, 5% and 16.2%, respectively [4], [16], [23]– [25].

Part of the success of the implementation is based on the commitment of both staff and top management. Therefore, the participation of the entire company is essential to obtain positive results [24], [26]. Likewise, applying and sustaining TPM is complicated, especially for small and medium-sized companies, because this strategy requires time and high-cost resources. However, a model called "light TPM" has been proposed, which is focused on the application of basic pillars such as: autonomous maintenance, training, and planned maintenance. Autonomous maintenance is a pillar designed to promote the ownership of the equipment in the operator, planned maintenance to reduce breakdowns and training is a pillar focused on personnel training [27], [28].

4. *Standardization and continuous improvement*

Product quality plays an important role in the manufacturing industry and influences customer satisfaction. Quality losses directly affect this premise, so multiple methods of continuous improvement have been developed. [9], [10], [29]. Among these methods, the Define-Measure-Analyze-Improve-Control (DMAIC) cycle stands out as it has a more accurate understanding of the process and fully measures its capability [6], [10], [30]. However, its application requires the use of other tools to improve the process. The implementation of standardization defines and replicates the standard execution of a process, reducing its variation over time [10], [30], [31]. With this integration, a reduction in the defect rate of 99% has been achieved [9], 97.6% [10], 78% [31] and 50% [32][6] demonstrating its effectiveness.

Minimizing the sources of quality loss requires the application of a continuous improvement method capable of analyzing and improving the process, as enhanced by the DMAIC cycle [6], [10]. Similarly, this improvement cycle is applied as a framework for improvement leading to standardization. Standardization uses the different stages of the DMAIC cycle to determine improvement opportunities, implement them, validate them, and apply or improve the standards to the process [30], [33].

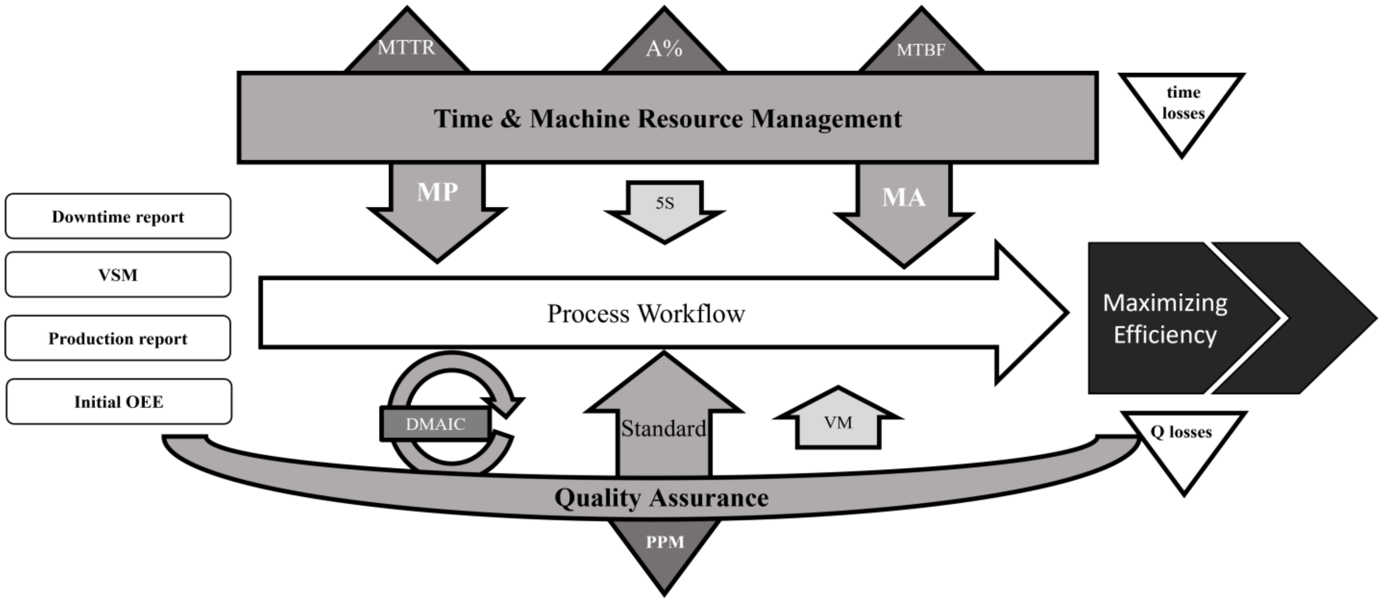

Fig. 1. Efficiency Maximization Model in a production line

III. CONTRIBUTION

A. Foundation

The proposed model was developed based on the analysis of the efficiency of a production line contemplating the entire process flow as the focus for improvement [13]. This analysis determines the sources of loss with respect to productive time and compliant production. In the case of losses due to unproductive time, these are related to the availability indicator, whose maximization is sought by reducing unplanned machine stoppages [4]. This requires the management of the time and machinery available for the execution of the process [13]. For losses associated with product nonconformity, process quality assurance is required [34]. To this end, the DMAIC cycle is used as a framework for the improvement of all production processes [6]. The relationship between these two aspects and their maximization over time directly affect the efficiency of the production line.

B. Proposed model

The proposed model proposes a balanced improvement approach covering both aspects: quality and maintenance. Likewise, its implementation is based on the limitations of labor capital and resources that an SME has.

As shown in Figure N°1, the focus of the Time & Machine Management component is to minimize time losses by maximizing availability and is based on the execution of the TPM pillars, autonomous and planned maintenance. The Quality Assurance component aims at reducing the sources of quality loss by minimizing the number of defects per million. The conjunction of these two components occurs throughout the production process flow and has as a joint objective the maximization of efficiency. The advantage of the implementation of this model is the complement existing in the same in guaranteeing a greater available time and an improved rate of conforming products.

C. Model detail

1) Time & Machine Management

The focus of the Time & Machine Management component is the minimization of time losses generated by machine breakdowns. To this end, it requires the evaluation of the initial OEE, the recording of machine stoppages and the implementation of the proposed tools: 5S and TPM pillars [5].

a) 5s methodology

The 5S is executed as a basic implementation tool to condition the space because the cleanliness and order of an area directly affect the way in which operators develop their activities. Likewise, delimiting areas, tools, equipment. facilitates the search and identification of these which in turn reduces unproductive times [4].

b) Autonomous Maintenance (AM)

The implementation of the AM is the central axis of improvement because it allows to train operators under a standard of basic activities which reduce the probability of a breakdown in the machine. In the same way, it allows to extend the machine's useful life through the conditioning of its components [35].

c) Planned Maintenance (PM)

The application of PM focuses on maintaining the machine at its highest level through periodic maintenance. With this, maintenance activities include inspection and basic conditioning of the equipment, for which a frequency is established to control and verify compliance with these activities [24].

The application of PM focuses on maintaining the machine at its highest level through periodic maintenance. With this, maintenance activities include inspection and basic conditioning of the equipment, for which a frequency is established to control and verify compliance with these activities [24].

2) *Quality Assurance*

Its objective is to minimize the sources of quality loss and, therefore, the defect rate. This component is based on the use of the production and defect record to mitigate their sources of losses through the analysis of the process that generates them. For this, the implementation of the standardization tool is required as a central axis through the DMAIC cycle due to its close relationship [6]. Likewise, as a complement, the Visual Management tool is proposed as the final link in the standardization process.

a) Standardization

Standardization is used to formalize the processes to be improved and to define the indicators that will govern the performance of these processes. To achieve this, the DMAIC cycle will be used as a continuous improvement framework. With this integration, the process to be improved will be defined, standardized, and controlled on a continuous basis [6].

b) Visual Management

Visual Management supports the standardization of processes by managing visual warnings that allow the identification of the actions to be performed by the operators, minimizing non-standard decisions [36].

D. Proposed process

Proposed Process for the implementation of the model is presented in the figure 2.

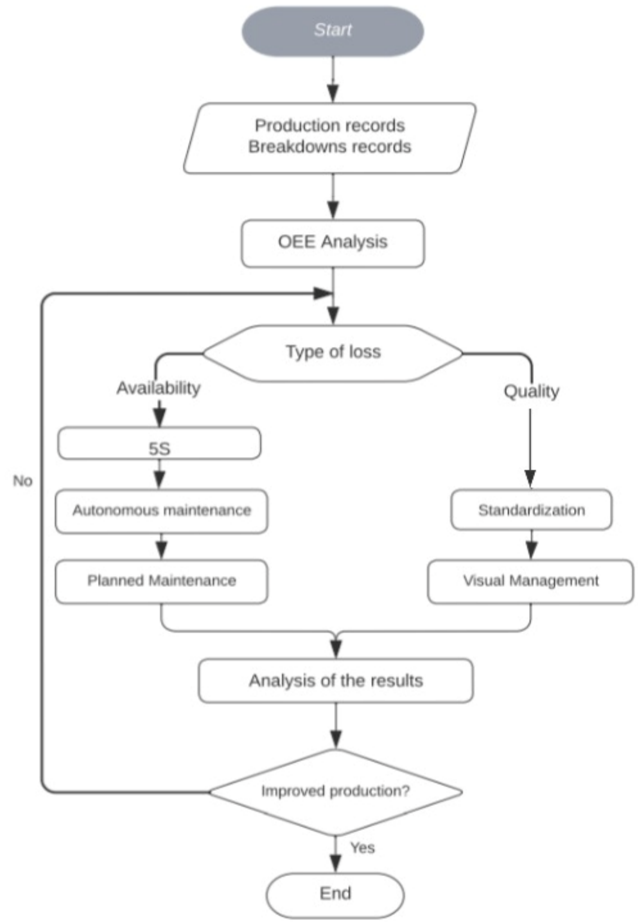

Fig. 2. Proposed Process

E. Model Indicators

a) OEE

This indicator measures the overall efficiency of the teams. Objective: Increase to 85% [3].

$$\text{OEE} = \text{Availability} \times \text{Performance} \times \text{Quality}$$

b) Availability

This indicator measures the percentage of time available for line operation. Objective: Increase to 90% [12], [13], [37].

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Planned Time}}$$

c) MTBF

This indicator measures the average time a machine operates without failure. Objective: Increase by 25% [4], [38].

$$\text{MTBF} = \frac{\text{Time Available - Stop Time}}{\text{Number of Stops}}$$

d) Quality

This indicator measures the percentage of line operation quality. Objective: Increase to 99% [38].

$$\text{Quality} = \frac{\text{Compliant production}}{\text{Total Production}}$$

e) Defects per Million

Measures the number of defects per Million. Objective: Decrease to <66k.

$$\text{PPM} = \frac{\text{Defects}}{\text{Sample}} \times 10\text{^}6$$

IV. VALIDATION

The case study is developed in an SME company of the plastics sector located in Peru. This company has a thermoforming production line in which the final product is a thousand polypropylene cups. The company's production process is shown in Figure 3.

For the analysis of line efficiency, the calculation method proposed by Muthiah and Huang in 2007 was used [15] which consider the analysis of the system in parallel within the complete production system. For this purpose, it is necessary to calculate the Availability, Yield and Quality for the period from July 2020 to June 2021. Therefore, the results of the calculation of the efficiency of each machine are presented in Table I and

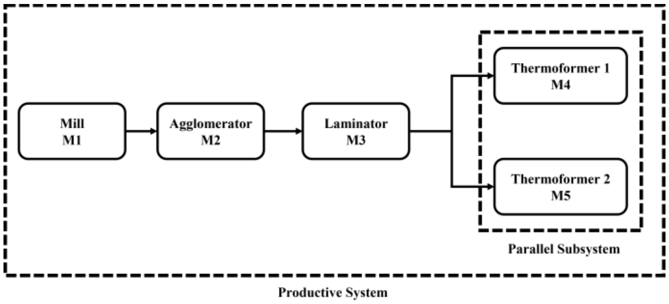

Fig. 3. Productive System

TABLE I
OEE CALCULATION PER MACHINCE

Machine	A	P	Q	OEE
M1	99.75%	100.00%	100.00%	99.75%
M2	99.58%	100.00%	100.00%	99.58%
M3	98.80%	97.68%	87.34%	84.28%
M4	88.74%	98.32%	77.48%	67.60%
M5	88.60%	98.18%	78.54%	68.32%

TABLE II
OEE CALCULATION FOR PRODUCTION LINE

Subsystem	OEEsub	Rth		SQeff	Bottleneck (Kg/h)
M1	99.75%	200	kg/h	100.00%	106.02
M2	99.58%	400	kg/h	100.00%	211.67
M3	84.28%	250	kg/h	87.34%	128.20
P1	67.96%	130.56	kg/h	78.01%	88.72

the results of the calculation of the efficiency of the line in Table II.

With this, the result of the overall efficiency of the production line amounts to 67.96% denoting the bottleneck in the subsystem comprised by the M4 and M5 machines, being the M4 machine the one with the lowest efficiency value.

The root cause associated with the loss of availability lies in the absence of conditioning on the machine components. Similarly, the root causes associated with quality losses are inadequate temperature settings and losses caused by product contamination. The proposed model will be implemented to mitigate these causes. The validation of the model will be carried out based on a pilot test on the M4 machine, since it is the one with the lowest efficiency.

A. Time & Machine Resource Management

a) Theoretical and practical training

To begin with, a training session was held, and the plant manager and 2 maintenance operators were invited. The purpose of this training was to introduce them to the theory and practice of applying the proposed tools. A document was signed and a TPM team was created to supervise and follow up on the proposed activities.

b) Basic conditioning

To improve order and cleanliness within the maintenance area, 5s were applied. In the first instance, an initial audit was carried out and a score of 30.67% was obtained, which meant that it was "Insufficient" with respect to the maximum value and improvement actions had to be taken. In this way, the elements were classified according to the following categories: equipment, tools, consumables, and spare parts. After that, the elements that belonged to another area or were considered defective were discarded. With this, the elements were relocated according to their frequency of use, i.e., those that were more frequent were placed in a place closer to the operator. In addition, the areas were delimited with signaling tapes: yellow for the aisles, red for flammable elements, orange for equipment, tools, spare parts, and consumables. To monitor the activities, a checklist was developed in which each cleaning and tidying task had a person in charge. With all the improvements implemented, a final audit was carried out, in which an increase of 49.33% was obtained with respect to the current situation.

c) Application of autonomous planned maintenance

For the application of autonomous maintenance, a schedule of initial inspection of the machine was developed with the objective of detecting and preventing future failures. Similarly, a lubrication, adjustment and cleaning standard were developed, detailing how the machine components should be adjusted or lubricated, and the frequency with which this should be done. Also, for continuous improvement of maintenance practices, a suggestion booklet was made available to the operators so that they could make any contribution with respect to the proposed standard.

For the application of planned maintenance, a schedule is developed based on the maintenance activities to be performed by the operators, and compliance with these activities is monitored. With this, a computer-assisted maintenance management (CMMS) is implemented in which machinery failures and available time are compiled. In the same way, based on the information entered, weekly reports are generated, which are useful to measure the MTBF and the availability of the machine and at the same time detect which components require further inspection before starting each production. Thus, after the pilot test, an increase in MTBF of 11.29% was evidenced.

B. Quality Assurance

a) Standardization of the environment

To reduce product contamination, which represents 4.7% of total production, the process execution conditions were standardized. For this purpose, a 3S audit was carried out, where initially a value of 33.3% was obtained with respect to the ideal.

<u>Sorting and Ordering</u>

With the classification and ordering, 25 elements were in the thermoforming area, of which 16 were relocated to the areas to which they belonged and 4 were discarded because they had no function.

<u>Cleaning</u>

An initial cleaning schedule was drawn up for the cleaning, which lasted one week. This schedule stipulated the cleaning methods and the people responsible for them.

Standardization of the environment

To standardize the cleaning conditions of the process, a procedure for mitigating sources of dirt was developed. This procedure contains a schedule by zone, frequency, responsibility, and cleaning method. This procedure contains a schedule by zone, periodicity, responsibility and cleaning method, and its execution is controlled over time through the cleaning control register.

With the implementation, the final audit was carried out, achieving a score of 86.7%, improving the initial conditions of the process.

b) Process standardization

For the standardization of the quality control process, the DMAIC cycle is executed in which an improvement is made on it to finally standardize and control it over time.

Define

The SIPOC diagram was used to define the critical process to be improved. From the analysis of this diagram, it was determined that the process responsible for the temperature configuration and its control over time is the Quality Control process. With this process defined, the quality circle team was formed.

Measure

The quality losses associated with the production process were measured and it was validated that 61.2% of the defects are caused by inadequate temperature settings and, in turn, represent 13.5% of the total production.

Analyze & Improve

As developed by Penix in 1991 on thermoforming process [39], you have been able to identify the required you on the current temperature configuration. The current configuration maintains an irregular distribution of the heat on which the polypropylene film is exposed. However, the recommendation is to make a uniform configuration where the temperature can reach the core of the sheet without generating the effect of thermal degradation.

The improvement of the process on the configuration was done through the development of the Quality Control procedure. This procedure includes the temperature change method according to the defect samples collected. Personnel training was carried out and a method of periodic review of daily defects was implemented.

Control

In the control phase, audits were conducted on the improved process and the SIPOC was updated with the improvements proposed. The indicators that will control the process were also determined.

c) Visual Management

This tool served as a complement to the standardization of the quality control process by placing information cards in the M4 machine. In addition, a visual board was installed with information pertinent to the production processes.

C. Results

With the implementation of Time & Machine Resource Management, MTBF was increased from 708 minutes to 788 minutes, which in turn allowed an increase in availability from 88.60% to 91.96%.

With the implementation of Quality Assurance, defects due to soiling were reduced from 4.7% of total production to only 0.93%. Similarly, defects due to temperature configuration were reduced from 13.5% to 5.51%.

Table III shows the As Is Vs To Be indicators of the case study, as well as the improvement achieved with the pilot test.

V. CONCLUSIONS

The conjunction of tools dedicated to the improvement of maintenance and quality processes in a machine belonging to the thermoforming line, have brought positive results in a short period of maturation of the model. The implementation of the maintenance component has as its focus the reduction of time losses due to machinery breakdowns that directly compromises the working time. With this implementation, the MTBF indicator exceeded the expected by 45 minutes and guaranteed an increase of 3.36% in Availability. The implementation of the component associated with quality improvement decreased the PPM defect rate from 215k to 115k reducing the gap to only 49k to reach 3 sigmas. With this reduction, the gap in the Quality indicator was cut to only 10.56% improving by 10.96% in the short implementation time of the pilot.

Through the implementation of the 5S, the maintenance agents were prepared for the improvement process with the implementation of the TPM pillars. The conjunction of these tools allowed the maintenance process to flow according to the immediate needs of the machinery and those planned for their attention. Thus, the responsibilities and involvement of the personnel were key factors in the success of the pilot implementation. With the standardization of the quality control process, the organization improved the parameterization of the configurations it exercised around the process. In the same way, the decision making of changes in the operating window changed from an empirical perspective to one determined by sampling and correction references [39]. Similarly, the standardization of cleaning activities improved not only the defect rate but also the work environment by taking place in a clean and orderly environment.

TABLE III
KPI EVOLUTION

KPI	AS IS	TO BE	Pilot	GAP
OEE	67.60%	85.00%	79.75%	5.25%
Availability	88.60%	90.00%	91.96%	-1.96%
MTBF	708 min	743 min	788 min	-45min
Quality	77.48%	99.00%	88.44%	10.56%
PPM	215k	66k	115k	49k

In summary, although the pilot plan was not able to achieve the goals set by the analyzed literature, its short implementation time has allowed considerable progress to be made. Therefore, with time to mature and its application throughout the production line, the objectives will be successfully achieved.

References

[1] Instituto de Estudios Económicos y Sociales (IEES), "Reporte Sectorial Plásticos N°04-2019 ," 2019.

[2] INEI, "Situación del Sector Plástico en el Perú Aspectos Cuantitativos," 2021.

[3] S. Nakajima, *Introduction to TPM: Total Productive Maintenance*. 1988. Accessed: May 04, 2022. [Online]. Available: https://books.google.com.pe/books/about/Introduction_to_TPM.html?id=XKc28H3JeUUC&redir_esc=y#:~:text=This%20was%20the%20first%20book,as%20much%20as%20150%20percent.

[4] G. Pinto, F. Silva, N. Fernandez, R. Casais, A. Baptista, and C. Carvalho, "Implementing a maintenance strategic plan using TPM methodology," *International Journal of Industrial Engineering and Management*, 2020, doi: 10.24867/IJIEM-2020-3-26.

[5] Z. Tian Xiang and C. Jeng Feng, "Implementing Total Productive Maintenance in a Manufacturing Small or Medium-Sized Enterprise," *Journal of Industrial Engineering and Management*, 2020, doi: 10.3926/jiem.3286.

[6] M. H. Sajjad *et al.*, "Waste reduction of polypropylene bag manufacturing process using Six Sigma DMAIC approach: A case study," *Cogent Eng*, vol. 8, no. 1, Jan. 2021, doi: 10.1080/23311916.2021.1896419.

[7] I. P. S. Ahuja and J. S. Khamba, *Total productive maintenance: Literature review and directions*, vol. 25, no. 7. 2008. doi: 10.1108/02656710810890890.

[8] F. Hardt, M. Kotyrba, E. Volna, R. Jarusek, and A. Carvalho, "Innovative Approach to Preventive Maintenance of Production Equipment Based on a Modified TPM Methodology for Industry 4.0," *Applied Sciences (Switzerland)*, p. 17, 2021, doi: 10.3390/app11156953.

[9] V. Gupta, R. Jain, M. L. Meena, and G. S. Dangayach, "Six-sigma application in tire-manufacturing company: a case study," *Journal of Industrial Engineering International*, vol. 14, no. 3, pp. 511–520, 2018, doi: 10.1007/s40092-017-0234-6.

[10] V. S. Patyal, S. Modgil, and M. Koilakuntla, "Application of Six Sigma methodology in an Indian chemical company," *International Journal of Productivity and Performance Management*, vol. 70, no. 2, pp. 350–375, Apr. 2020, doi: 10.1108/IJPPM-03-2019-0128.

[11] D. R. Veit, P. N. de Lima, D. P. Lacerda, D. C. Collatto, and A. Dresch, "Inducing Brazilian manufacturing SMEs productivity with Lean tools," *International Journal of Productivity and Performance Management*, vol. 68, no. 1, pp. 69–87, 2018, doi: 10.1108/IJPPM-10-2017-0248.

[12] C. K. Cheah, J. Prakash, and K. S. Ong, "An integrated OEE framework for structured productivity improvement in a semiconductor manufacturing facility," *International Journal of Productivity and Performance Management*, vol. 69, no. 5, pp. 1081–1105, May 2020, doi: 10.1108/IJPPM-04-2019-0176.

[13] P. Tsarouhas, "Improving operation of the croissant production line through overall equipment effectiveness (OEE): A case study," *International Journal of Productivity and Performance Management*, vol. 68, no. 1, pp. 88–108, 2019, doi: 10.1108/IJPPM-02-2018-0060.

[14] P. Muchiri and L. Pintelon, "Performance measurement using overall equipment effectiveness (OEE): Literature review and practical application discussion," *Int J Prod Res*, vol. 46, no. 13, pp. 3517–3535, 2008, doi: 10.1080/00207540601142645.

[15] K. M. N. Muthiah and S. H. Huang, "Overall throughput effectiveness (OTE) metric for factory-level performance monitoring and bottleneck detection," *Int J Prod Res*, vol. 45, no. 20, pp. 4753–4769, 2007, doi: 10.1080/00207540600786731.

[16] I. Zennaro, D. Battini, F. Sgarbossa, A. Persona, and R. de Marchi, "Micro downtime," *International Journal of Quality & Reliability Management*, vol. 35, no. 4, pp. 965–995, Apr. 2018, doi: 10.1108/IJQRM-11-2016-0202.

[17] M. Braglia, M. Frosolini, and M. Gallo, "Overall material usage effectiveness (OME): a structured indicator to measure the effective material usage within manufacturing processes," *Production Planning & control*, 2018.

[18] J. Randhawa and I. Ahuja, "AN INVESTIGATION INTO MANUFACTURING PERFORMANCE ACHIEVEMENTS ACCRUED BY INDIAN MANUFACTURING ORGANIZATION THROUGH STRATEGIC 5S PRACTICES," *International Journal of Productivity and Performance Management*, 2018.

[19] Y. Schoeman, P. Oberholster, and V. Somerset, "Value stream mapping as a supporting management tool to identify the flow of industrial waste: A case study," *Sustainability (Switzerland)*, vol. 13, no. 1, pp. 1–15, 2020, doi: 10.3390/su13010091.

[20] C. O. Chan and H. L. Tay, "Combining lean tools application in kaizen: a field study on the printing industry," *International Journal of Productivity and Performance Management*, vol. 67, no. 1, pp. 45–65, 2018, doi: 10.1108/IJPPM-09-2016-0197.

[21] S. Kumar, A. K. Dhingra, and B. Singh, "Kaizen Selection for Continuous Improvement through VSM-Fuzzy-TOPSIS in Small-Scale Enterprises: An Indian Case Study," *Advances in Fuzzy Systems*, vol. 2018, pp. 1–10, Jul. 2018, doi: 10.1155/2018/2723768.

[22] S. I. S and V. Bahtt, "Lean Manufacturing Implementation Using Value Stream Mapping with

Simulation to Reduce Cycle Time and Improve Productivity in Valve Manufacturing Unit.," *IUP Journal of Operations Management*, vol. 19, no. 1, pp. 21–39, 2020, [Online]. Available: http://search.ebscohost.com/login.aspx?direct=true&db=bth&AN=144553697&site=ehost-live

[23] N. Ahmad, J. Hossen, and S. M. Ali, "Improvement of overall equipment efficiency of ring frame through total productive maintenance: a textile case," *International Journal of Advanced Manufacturing Technology*, vol. 94, no. 1–4, pp. 239–256, Jan. 2018, doi: 10.1007/s00170-017-0783-2.

[24] J. Singh, H. Singh, and V. Sharma, "Success of TPM concept in a manufacturing unit – a case study," *International Journal of Productivity and Performance Management*, vol. 67, no. 3, pp. 536–549, 2018, doi: 10.1108/IJPPM-01-2017-0003.

[25] A. Muñoz-Villamizar, J. Santos, J. Montoya-Torres, and M. J. Alvaréz, "Improving effectiveness of parallel machine scheduling with earliness and tardiness costs: A case study," *International Journal of Industrial Engineering Computations*, vol. 10, no. 3, pp. 375–392, Jul. 2019, doi: 10.5267/j.ijiec.2019.2.001.

[26] J. Reyes, K. Alvarez, A. Martínez, and J. Guamán, "Total productive maintenance for the sewing process in footwear," *Journal of Industrial Engineering and Management*, vol. 11, no. 4, pp. 814–822, 2018, doi: 10.3926/jiem.2644.

[27] O. Bataineh, T. Al-Hawari, H. Alshraideh, and D. Dalalah, "A sequential TPM-based scheme for improving production effectiveness presented with a case study," *J Qual Maint Eng*, vol. 25, no. 1, pp. 144–161, Mar. 2019, doi: 10.1108/JQME-07-2017-0045.

[28] Z. Tian Xiang and C. Jeng Feng, "Journal of Industrial Engineering and Management Implementing Total Productive Maintenance in a Manufacturing Small or Medium-Sized Enterprise", doi: 10.3926/jiem.3286.

[29] A. Realyvásquez-Vargas, K. C. Arredondo-Soto, T. Carrillo-Gutiérrez, and G. Ravelo, "Applying the Plan-Do-Check-Act (PDCA) Cycle to Reduce the Defects in the Manufacturing Industry. A Case Study," *Applied Sciences (Switzerland)*, 2018, doi: 10.3390/app8112181.

[30] R. S. Mor, A. Bhardwaj, S. Singh, and A. Sachdeva, "Productivity gains through standardization-of-work in a manufacturing company," *Journal of Manufacturing Technology Management*, vol. 30, no. 6, pp. 899–919, Oct. 2019, doi: 10.1108/JMTM-07-2017-0151.

[31] C. J. Moin, A. B. M. S. ud Doulah, M. Ali, and F. Sarwar, "Implementation of an operating procedure for quality control at production level in a RMG industry and assessment of quality improvement," *The Journal of The Textile Institute*, vol. 109, no. 4, pp. 524–535, Apr. 2018, doi: 10.1080/00405000.2017.1358412.

[32] A. Adeodu, M. G. Kanakana-Katumba, and M. Rendani, "Implementation of Lean Six Sigma for production process optimization in a paper production company," *Journal of Industrial Engineering and Management*, vol. 14, no. 3, p. 661, Jul. 2021, doi: 10.3926/jiem.3479.

[33] A. Realyvásquez Vargas, K. C. Arredondo Soto, J. Blanco Fernandez, J. D. Sandoval Quintanilla, E. Jiménez Macías, and J. L. García Alcaraz, "Work Standardization and Anthropometric Workstation Design as an Integrated Approach to Sustainable Workplaces in the Manufacturing Industry," *Sustainability*, vol. 12, no. 9, p. 3728, May 2020, doi: 10.3390/su12093728.

[34] A. Realy vásquez-Vargas, K. C. Arredondo-Soto, T. Carrillo-Gutiérrez, and G. Ravelo, "Applying the Plan-Do-Check-Act (PDCA) Cycle to Reduce the Defects in the Manufacturing Industry. A Case Study," *Applied Sciences (Switzerland)*, 2018, doi: 10.3390/app8112181.

[35] O. Bataineh, T. Al-Hawari, H. Alshraideh, and D. Dalalah, "A sequential TPM-based scheme for improving production effectiveness presented with a case study," *J Qual Maint Eng*, vol. 25, no. 1, pp. 144–161, Mar. 2019, doi: 10.1108/JQME-07-2017-0045.

[36] F. Gaspar and F. Leal, "A methodology for applying the shop floor management method for sustaining lean manufacturing tools and philosophies: a study of an automotive company in Brazil," *International Journal of Lean Six Sigma*, vol. 11, no. 6, pp. 1219–1238, Dec. 2020, doi: 10.1108/IJLSS-09-2019-0098.

[37] J. Singh and H. Singh, "Application of lean manufacturing in automotive manufacturing unit," *International Journal of Lean Six Sigma*, vol. 11, no. 1, pp. 171–210, 2018, doi: 10.1108/IJLSS-06-2018-0060.

[38] J. Singh and H. Singh, "Justification of TPM pillars for enhancing the performance of manufacturing industry of Northern India," *International Journal of Productivity and Performance Management*, vol. 69, no. 1, pp. 109–133, Jan. 2020, doi: 10.1108/IJPPM-06-2018-0211.

[39] J. A. Penix, "Thermoforming of Plastic Film and Sheet," in *SPI Plastics Engineering Handbook of the Society of the Plastics Industry, Inc.*, Boston, MA: Springer US, 1991, pp. 383–427. doi: 10.1007/978-1-4615-7604-4_13.