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Production management model under the Lean approach to reduce the waste rate in the manufacturing process of SMEs in the ceramic sector

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Abstract*— Ceramic manufacturing plants base their operations around continuous and automated production, prioritizing the proper maintenance of machines to avoid production losses. In this sense, this research focuses on reducing defective products since it generates the greatest economic loss in the case study. For this purpose, a production management model based on TPM and SMED tools is proposed, contributing to the increase of availability and reduction of the mean time between machinery failures. Finally, the results are validated based on the line production, which represents 33.55% of the monetary value. Finally, the proposed model manages to decrease the set-up time and increase the availability of machinery to 32.31% and 88.4%, respectively, obtaining as a critical result the reduction of defective products from 5.44% to 1.97%, allowing access to a high level of competition in its sector and a decrease in operating cost overruns.

***Keywords*—Lean manufacturing, defective products, preventive maintenance, TPM, SMED, OEE**

I. Introduction

The import and export rate of ceramic tiles in Peru has been increasing. Figures from the National Institute of Statistics and Informatics (INEI) mention that the Free on Board (FOB) export value of ceramic or glazed tiles increased by 76.20% from $ 11 million in 2005 to $ 96 million in 2018, generating employment; the sector represents a little more than 2% of permanent employment corresponding to the manufacturing category [1]. Therefore, it is crucial to solving the problems that mitigate in the organizations involved with the ceramics industry.

One of the main activities that contribute to the increase in Gross Domestic Product (GDP) is the export of ceramic tiles, which has shown an annual growth of 7.04% worldwide in the last ten years [1]. The reason is that the fabrication of these goods is part of the construction sector, which occupies an important place in the global economy since the requirement of infrastructure is one of the first needs for the development of urbanization. [3].

On the other hand, in manufacturing, it is crucial to increase the production rate and improve quality standards, especially on the surface of tiles. It is necessary to face the problems involved in the automation of processes, except for quality inspection, which essentially involves human intervention for its approval [4] [5]. Another difficulty is the increase in defective products, related to several factors belonging to the global Ishikawa framework, such as human, machine, material, environment, method, and measurement [6]. It is essential to mention that the defective product is part of the seven groups of waste classified by the Toyota production system. Therefore, efforts to minimize them must involve using tools based on a lean manufacturing approach to reduce losses in the operating processes. [7]

In the literature research, it was possible to evidence the number of successful case studies on Lean methodology in the manufacturing industry. That the case studies evidenced a problem of defective products, so researchers implemented Lean management tools. In that sense, the objective of this study is to design a production management model which contributes to the reduction of defective products, so that the efficiency of the production lines is increased, improving quality, and allowing access to a high level of competition in its sector and reducing operating cost overruns. In the same way, one reason that motivates us to do this research is that treating waste generated in a plant is essential for sustainability. The benefit of treating or reduction of defective products helps reduce process energy demand.

For this reason, the solution to the problem to be presented is environmentally friendly. This article consists of a state-of-the-art stage in which the literature review that supports the research proposal is evidenced. Then we move on to the contribution phase, in which the study methodology is described. Similarly, a validation stage is presented, where the

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case study is analyzed, and the results are obtained—finally, a section of conclusions.

II. LITERATURE REVIEW

A. TPM in maintenance processes in the manufacturing sector

Total Productive Maintenance (TPM) is a defined method that eliminates and identifies high reprocessing times that machines have spontaneously [8]. Likewise, several authors consider that integrated management of Total Productive maintenance can improve production line's efficiency where measurements and inspections can be made through OEE [9]. However, the main result of the manufacturing companies was the increase in their production and high-performance level, which focused on operator training and continuous improvements in the work environment so that total productive maintenance could be applied correctly [10]

In this sense, the present research wants to implement the TPM tool since it would help to reduce reprocesses and increase the availability of the machines, which leads to a reduction of defective products that is consequent by spontaneous stops in the process. In the previously mentioned studies, there needs to be research in the ceramic tile sector, which is considered necessary research for the presented project since it would validate how it would be to implement this tool. [11].

B. SMED in companies for set-up reduction

According to several authors, they consider that to reduce waste in production, it is crucial to have good tools such as SMED (Single Minute Exchange of Die) since it focuses on lowering machine configuration times or also known as set up times, which helps to minimize the internal steps of the configuration process so that the production has a more extended time [12][13]. Likewise, other authors used manufacturing companies the SMED tool in which analysis and a brief description were made detailing different types of processes that are associated with the products, which had as an optimal value the set-up time with a significant reduction of 55.60% and achieving a decline of 81.62% in the set-up time. Therefore, the SMED tool has been considered one of the tools which significantly resulted in reducing downtime [14].

In this sense, the present research wants to implement the SMED tool since previous studies mentioned above highlight that it would help to reduce set-up times, which leads to a reduction of defective products in the ceramic tile sector because it would reduce unnecessary activities in the manufacturing processes which are potential causes of faulty parts. However, previous studies have yet to find research focusing on the ceramic sector to reduce set-up. Therefore, our research is essential for this sector which would help to control the activities in similar processes that can execute.

C. TPM and SMED in manufacturing companies

According to previous studies, some authors mention how the tools of total preventive maintenance and SMED allow the correct provision of the techniques for operators in the processes since the operators who deal with the care of machines should have a solid foundation base, which allows them to have better development and have; as a result, a standardized work [15].

Likewise, what should note that other authors consider that all these activities that are being performed in preventive maintenance are of high importance to identify the reprocesses that can be found and verify the activities that enable early detection of anomalies in equipment and plant machinery [24]. The autonomous maintenance that belongs to the TPM joins the SMED tool since, in the care, it is understood with the constant activities that are performed as the daily checklist, calibrations, verifications, and machine adjustment, among other activities that are performed in the maintenance and that can be optimized using the SMED tool [16] [17]

In addition, as other authors mention, it is considered the benefits that manufacturing companies can have in the process, such as improved machine availability and, consequently, greater production efficiency. Also, the tools work and adequately involve the increased knowledge, responsibilities, and skills that operators may have, which can be highlighted in the processes [18].

D. Lean manufacturing for the reduction of defective products

The central concept of this study is to analyze the production behavior in the manufacturing sector based on data and tools proposed by author(s) who have sought to provide solutions to problems such as quality, waste reduction, and defective products. For this, it is necessary to define Lean Manufacturing or Lean Manufacturing. This can be summarized in the management practices that make changes in the manufacturing processes generating the reduction of time and waste, as well as flexibility and cost reduction. [18] [19]. Furthermore, the type of Lean Manufacturing implementation creates a complete organizational change, change in management, the administrative area, the supply chain, and the daily work of all personnel [20].

III. CONTRIBUTION

A. Basis

The proposed model is based on case studies, where LM tools have played an essential role in defining the main problem from the waste analysis [21][22]. The most relevant diagnostic tools used were VSM and ABC charts because whit these was possible to trace in the entire process the non-value activities. For that reason, these tools are used in our research to identify bottlenecks and potential critical points that affect the efficiency of the production line by increasing the number of defective products. In addition, applying this model leads to have a cultural change in all areas to the process that you want to apply the company. Because it will have to be executed phase by phase, with a long-term commitment to those involved in improvement activities from the beginning, since no change can be initiated in the way of working without having the people who will then work with these changes and thus can be observed compliance with the proposed indicators.

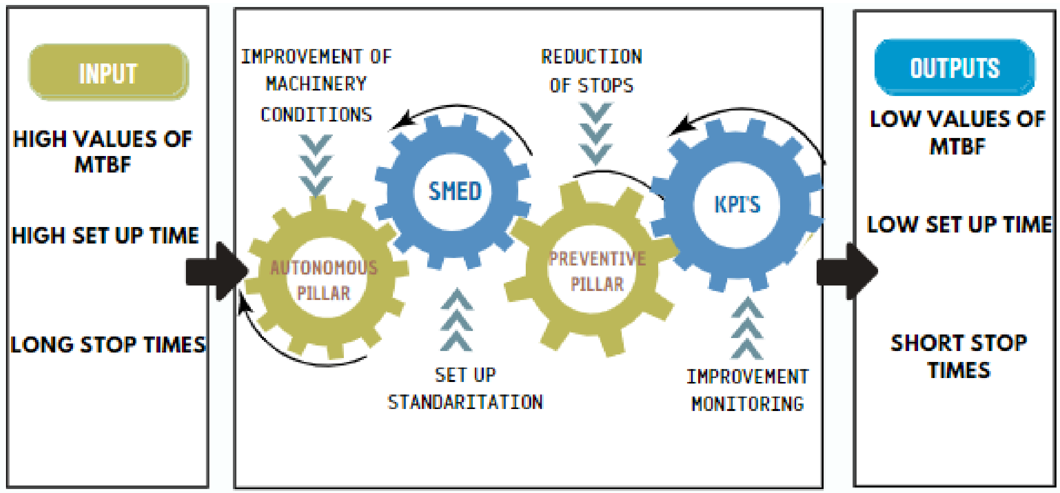

Fig. 1. Proposed model. Adapted from: [23] [24] [26] [14] [10].

B. General model of proposal

The case study analyzed in this research presents problems of high rates of defective production in its manufacturing sub-processes. According to the historical data for December 2021, this value was 5.46%. After the analysis with the diagnostic tools, efficiency problems were identified in the press and dryer machines, with values of raw material waste in the process of 4.4% and 3.49%, respectively. In addition, the availability for the month analyzed was 93.2%. The same analysis has been made for the plant's furnaces, whose availability percentage was 89.90%. This affects the line's efficiency since, due to internal organizational issues, this defective production is not considered within the net output of the line.

This research has developed the LM model, based on TPM and SMED, to reduce the defective production rate and increase the efficiency of presses and dryers. Furthermore, this study aims to disseminate and validate the use of LM methodology in a new and little-studied scenario in the literature, thus seeking to establish a benchmark to contribute to the optimization of processes in the ceramic sector, increasing the products that exceed quality standards. Therefore, it is essential to promote the use of the model of this research, which integrates TPM tools, SMED, cards, instructions, and work procedures, in four components in a new sector.

Through this model, an increase in machinery availability of 60% is expected, which will be given as the main tools TPM and SMED. Likewise, it will be possible to determine the increase in the average time between stops with the simulation process. The Implementation of financial indicators such as VAN and IRR will also be carried out, to obtain a real investment of the improvement proposal. Figure 1 shows the proposed model to reduce the rate of defective production.

C. Design of the proposed method

Figure 2 shows the steps of the general model proposed—components in different steps group the stage of the flow of the process.

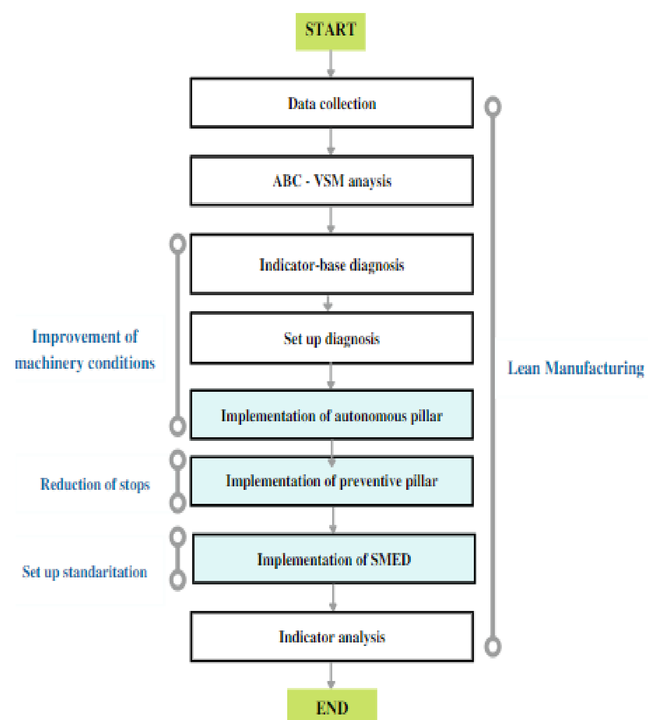

Fig. 2. Proposed Model Process

D. Indicator Analysis

Indicators are presented to measure the performance of the model.

• Percentage of defective production

Several studies mention that the value of the metric should not exceed 2.50% [21][22]

$$\% \, Defective = \frac{\text{m}^2\text{of unpackaged production}}{\text{m}^2\text{of total furnace production}} \text{x100\%} \quad (1)$$

• Percentage of quality

Is the quantity of packaged production

$$\%Quality = \frac{Proper\ Packaged}{Total\ Packaged} \quad (2)$$

• Percentage of set up reduction

Several studies mention that the value of the reduced time should be at least 30% of its original value. [14][15]

$$\% \, Setup\ time = \frac{\text{Standardized time}}{\text{Initial set-up time}} \text{x100\%} \quad (3)$$

• Availability:

According to several authors, the value of this indicator for continuous production should be 98%. [16][17]

$$\%Availability = \frac{\text{Operating time}}{\text{Available time}} \text{ x 100\%} \quad (4)$$

• Performance rate

According to several authors, the value of this indicator for continuous production should be 89%. [4][19]

$$\%Performance = \frac{\text{Cycle x items}}{\text{Total of items}} \text{x100\%} \quad (5)$$

• Overall Equipment Effectiveness (OEE)

According to several authors, the value of this indicator for continuous production should be at least 95%. [10][21]

$$\%OEE = \%Availability \times \%Quality \times \%Performance$$

IV. VALIDATION

This segment will present the validation of the model, which is divided into four parts: Description of scenario representation, initial diagnosis by the research company, simulation design and results.

A. Description of scenario representation

To demonstrate the effectiveness of the designed model, we did a simulation in which the system uses the main current production line of the successful case as the basis of the model. Likewise, to comply with the system's characteristics, the number of processes will adjust the number of operators and the data collected. Then, the batches are considered transit entities, and the operators in each work process are considered permanent entities. So, the graphical representation of the system was made to improve its understanding of the initial diagnosis.

B. Inicial diagnosis

The problem to investigate in the case study is that the company has been producing more than 2.5% of square meters of defective tiles so far in a period in year 2021. So far, this issue represents 7.38% of the total production costs. Significant amounts support the study of the proposed topic. Finally, it is essential to point out that concerning the configuration time that is being executed in the Product Change and Stamp Change processes, they have 14.01 min and 12.1 min respectively, per 8-hour shift, which means that, now of carrying out each circle, generate losses of ceramic coating products.

C. Simulation design

A design of the processing system of the present study was carried out in the Arena Simulator version 16.00 with numbers of replications of 30 times for corroborate the expected results of the present model proposal, which is represented in Figure 3. The system uses the main current production line of the as-is case as a model base. Likewise, to comply with the system's characteristics, the number of processes will adjust the number of operators and the data collected. Then, the batches are considered transit entities, and the operators in each work process are considered permanent entities. So, the graphical representation of the system was made to improve its understanding. In figure 03, it's possible to see the entities. Preparation of Raw Material: The raw material for manufacturing ceramics consists mainly of clays and processed additives. For this, it is necessary to pass through a grinding area, in which granulated mass is obtained, which will give to a pressing machine.

D. Results

Table 1 shows the result of the configuration of the simulator. The proposed model was able to obtain good values of set-up time reduction in the Pressing and decorating areas and increased the availability of machinery to 32.31% and 95.20%, respectively; receiving as a critical result the removal of defective products from 5.44% to 1.97% allowing to meet the objective set so that it can improve as competition in its sector and obtaining a decrease in operating cost overruns. Figure 03 shows the simulation of the system representation in Arena.

On the other hand, the evaluation of the economic impact will be validated with financial indicators of Net Present Value (NPV) and Internal Rate of Return (IRR), considering the amount of the research budget, which is S/. 78,100.00 and the results of the simulation program. As a first, it is observed that the net cash flow values do not identify negative values, therefore, it is observed that in the three scenarios there are no economic losses resulting at the end of the first year of the loan. It's important to highlight the optimistic scenario, it is found that the NPV is S/. 366,772.15 and the IRR is 91.20%. What this means is that, at the end of the 5 years of investment, the total NPV is recovered in profits and that for each sol invested, profits of S/0. 9120.

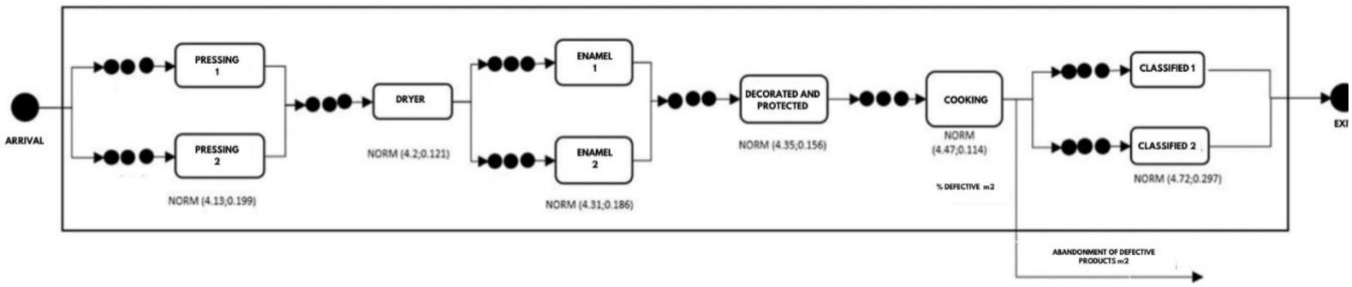

Fig. 3. Representation of current system

The application of this model implies some limitations and difficulties. One of them is the monitoring and control of OEE's indicators in a medium and long term. It's important to consider that to get good values of this rate depends on the constant practice of the lean culture and TPM and SMED tools. Also, there are other factors that can influence it, for example human interaction, organizational structure, corporate policies [25].

TABLE I. AS IS VS IMPROVED SITUATION

	Posible Scenery			
INDICATORS	***AS IS***	***Scenery 1***	***Scenery 2***	***Scenery 3***
Set up de PRODUCT CHANGE	28.02	24.1	15.23	10.1
Set up de CHANGE OF STAMP	24.2	20.3	12.7	5.74
Availability	85.97%	86.30%	91.75%	95.20%
Time stopped	1,216.46	1,187.63	715.18	416.10
Available time	8,668.80	5,470.87	7,586.10	8,668.80
Operating time	7,452.34	7,481.17	7,953.62	8,252.70
Performance	94.51%	95.76%	97.48%	98.72%
Finished production	7,272,000	7,368,000	7,500,000	7,596,000
Production capacity	7,694,173	7,694,173	7,694,173	7,694,173
Quality	93.04%	94.27%	96.00%	98.03%
% Defective production	6.96%	5.73%	4.00%	1.97%
Defective	506,170	422,400	300,000	150,000
Total production	7,272,000	7,368,000	7,500,000	7,596,000
OEE	75.59%	77.90%	85.86%	92.13%
Time stopped due to faults	1,216.46	1,187.63	715.18	416.10

V. CONCLUSIONS

In the manufacturing industry, there are tools that contribute to production control and management. Such is the case with the use of Value Stream Mapping (VSM) and the ABC diagram, which have provided us with important information about the level of waste in the production line. In the company analyzed, we have identified the bottleneck at the passage from the presses to the dryer, which has a considerable percentage of waste, as well as at the kiln exit. With the ABC, we have valued the lines, it has been concluded that there is no significant difference between them, being these that are within 30% to 35% of the total valorization of the production of the plant. Therefore, we proceed to quantify the causes of defective production.

To reduce the main problem discussed in previous lines, the implementation of tools aimed at reducing defective production, in this case, TPM and SMED, have contributed to improving indicators such as availability, efficiency, quality, OEE, and set-up. In this case study, according to the simulation report, a set-up time reduction for stamp changeover and 76.2% for product changeover is expected, implementing the SMED tool in an optimistic scenario. In terms of OEE values, an expected value of 92.13% placed the company in world-class values under the same circumstances.

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