Production Process Improvement Model Using TPM, Standardized Work and 5S Tools to Reduce Waste in the Metallurgical Sector

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Keywords: Metallurgy Sector, Improvement Model, Standard Work, 5S, Total Productive Maintenance.

Abstract: The metallurgical industry has had a positive influence on Peru's economic development in recent years. On the other hand, problems are observed within the sector under study, such as the high percentage of waste in production processes, which leads to the generation of high costs for the various companies. Due to this, the present research article seeks to propose engineering solutions focused on the reduction of wastes by means of Lean Manufacturing tools within which TPM (Total Productive Maintenance), Standard Work and 5S were integrated. Through the simulation in Arena software, the results of the research were extracted obtaining indicators that represented an improvement in the analyzed system. The OEE (Total Equipment Effectiveness) increased from 72% to 84%, the casting waste decreased from 3% to 2.6%, the percentage of waste in cuts from 3% to 1.8%. Finally, the high scrap rate in the production process was reduced from 7.64% to 6.20%.

1 INTRODUCTION

The metallurgical sector has a very important impact on the economic development of countries worldwide. One of the most attractive non-ferrous metals is copper, due to its applications in different types of drawing, tubes, sheets, bars and sections (C. Ayala et al., 2018). According to Euromonitor (2021), despite the fact that in Latin America the export of copper as raw and processed material has significantly decreased, it is still a source of high-yielding income, as it remains at around US$140 million. With respect to countries outside Latin America, the metallurgical sector stands out to a large extent in Spain, looking at it from an economic point of view. This is due to the fact that the country's industrial production is close to 40% and its gross value added is approximately 9.5% of Spain's GDP (Gross Domestic Product) (Carbajo et al., 2011, p.15).

According to the literature, for the problem identified, regarding pyrometallurgical processes in copper extraction, an approximate value of 2.2 tons of slag per 1 ton of metal produced is estimated. Most of the world's copper production (80-90%) comes from sulfide ores that require high temperatures for oxidation. However, the performance of these metallurgical processes generates a large amount of waste (Echeverry et al., 2016, p.60). Another literary research, according to Kuznetsov (2017), refers to the cutting processes and the precision of the machine when performing such cutting, being able to cause errors and waste due to dimensional accuracy, configuration of the machined parts, poor roughness and even vibrations during the cutting process (Kuznetsov, 2017). Other factors that directly affect the excessive production of shrinkage are failures in visual quality control or quick measurements, which occur in the various metal manufacturing processes. Considering the technological advances and the high precision machinery to which it gives access, human error has been one of the most critical factors in terms of quality control. According to Carrillo-Gutiérrez, T., Reyes-Martínez, R. M., Arredondo-Soto, K., & Solis-Quinteros, M. (2021) 70% to 90% of the quality defects in production systems are of this nature, which causes the generation of waste due to rejected products (Carrillo et al., 2021).

Due to the problems observed above, it is essential to emphasize that companies in the metallurgical sector in Peru should achieve greater efficiency in

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Gamarra, J., Sandoval Tirado, J. and Flores-Perez, A.
Production Process Improvement Model Using TPM, Standardized Work and 5S Tools to Reduce Waste in the Metallurgical Sector.
DOI: 10.5220/0012056100003612
In *Proceedings of the 3rd International Symposium on Automation, Information and Computing (ISAIC 2022)*, pages 812-817
ISBN: 978-989-758-622-4; ISSN: 2975-9463

terms of waste generation in the processes. One of the problems identified is the slag losses produced in the smelting process that cause a decrease in the yield of the raw material and, on the other hand, the wastes generated by the cutting and profiling processes are recognized. These cause a percentage of monetary losses of 8.53% of the company's profit in the case study. Therefore, to solve the problem, an improvement strategy was developed based on the use of two Lean Manufacturing tools: TPM, Standard Work and 5S.

This article will address seven parts, which are the State of the Art, in which the concepts of Standard Work, 5S and TPM obtained through the literature review will be developed. In addition, the contribution will be presented in which the proposed model, the components and its indicators will be observed. Next, a validation of the presented model will be presented, with detailed findings. Finally, the results and discussion will be presented.

2 STATE OF THE ART

For the present research, three typologies developed from the preliminary literature review were considered. These will be presented in the following paragraphs.

2.1 Lean Manufacturing in the Metallurgic Sector (Standardized Work)

Standardized work is a very effective Lean Manufacturing methodology when dealing with processes that involve manual labor in sequential processes. This is why we chose to analyze a study conducted by Fin, J. C., Vidor, G., Cecconello, I., & Machado, V. D. C. (2017) in which standardized work is implemented in a medium-sized chassis assembly line belonging to a company located in southern Brazil. What stands out in this case study is the thorough analysis of the production mechanism separating the study of materials and tools from labor and machinery. With this information, the minimum and optimum speeds for the production of the product were calculated, as well as the characteristics of the machinery.

On the other hand, the different types of waste that exist in the processes were determined. Through the preparation of a production capacity sheet, standardized routines for the operations were determined and consolidated in a document that was used in personnel training. As a result of the implementation, after one month, assembly time was reduced by 36 minutes, movements were reduced by 200 meters on average and by 5 stops to search for spare parts and tools. In conclusion, cycle time was reduced by 15%, operator movements by 34% and downtime by 9.6%. One of the aspects to be rescued from this case study is the continuous verification of compliance with the objectives, as well as the focus on waste reduction, since this can be focused on reducing waste in production (Fin et al., 2017).

2.2 Lean Manufacturing in the Metallurgic Sector (5S)

In this case, the 5S methodology was applied, dividing the steps into their respective points to be dealt with in their execution (M. Mau et al., 2019).

- *Select:* The "RED TAG SYSTEM" is used, which consists in the use of 2 types of cards. The red card for objects to be removed and the yellow card for objects to be repaired or changed.
- *Order:* Each tool must be in its respective assigned place. In this case, 5 labels are used that correspond to different categories (raw materials, quality control materials, production materials, Personal Protective Equipment and stationery).
- *Cleaning:* The visualization technique is used to have a better perception of the results. In addition, a cleaning plan and a cleaning kit per operator are proposed.
- *Standardize:* Procedures are established based on the three previous stages, defining a cleaning manual and production planning.
- *Maintain:* Staff is trained and audit plans are carried out. Monitoring of the 5S system is checked.

2.3 Total Productive Maintenance in the Metallurgic Sector (Mantenimiento Preventivo)

Considering another research conducted by Joshi, A. G., & Bagi, J. S. (2015) a gray iron smelting plant located in India. Through said study, important analysis techniques are applied such as overall equipment effectiveness (OEE), which is denoted under the formula "OEE = Availability * Performance * Quality"; maintenance and performance history charts; statistical graphs, Pareto and the cause-effect diagram. Such applied tools form a specific methodology that can be used as a model.

From this investigation, recommendations were obtained for the smelting plant, which included a change in the design of the pattern to provide adequate ventilation, verification of the permeability and moisture content of the sand and maintaining it at the required values, among others. As a result of the application of the methods, several studies were conducted over a period of three months. These yielded formidable results in which the quality indicator increased from 0.96 to 0.98, the performance indicator increased from 0.72 to 0.82, the quality indicator increased from 0.92 to 0.97 and, finally, the OEE indicator increased from 0.65 to 0.79 (Joshi, A. G. et al., 2015).

3 CONTRIBUTION

3.1 Basis

Nowadays, the metallurgical industry has become very competitive, both for medium and large companies. This is why it is of utmost importance to remain relevant in today's market, so it is necessary to have control over the waste produced in the processes, especially when working with large volumes.

Due to this, several methodologies and tools have been investigated with the purpose of solving the excessive production of wastes. Therefore, we have chosen to use the TPM (Total Productive Maintenance), Standardized Work and 5S methodologies, which will allow us to comply with the identified standards, benefiting both the customer and the company.

Table 1: Comparison matrix of the proposed components vs. State of the art.

Authors	**Planning**	**Waste management**	**Maintenance management**
Dinis, C. J., et al. (2019)	VSM	x	x
Assis & Carmona (2021)	x	x	TPM
Mau, M., et al. (2019)	x	5S	x
Lu, J., C., & Yang, T. (2015).	x	Standard Work	x
Madanhire, I., & Mbohwa, C. (2015)	x	x	TPM
Proposal	**VSM**	**Standard Work & 5S**	**TPM**

3.2 Proposed Model

The proposed model is based on three models: Standard Work Model, 5S and TPM methodology. These three methods will work in synergy focusing on meeting the expectations defined above.

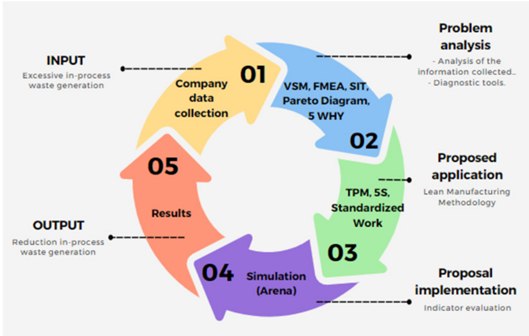

Figure 1: Proposed waste reduction model.

3.3 Model Components

3.3.1 Component 1: Problem Analysis

This was done with the help of a VSM (Value Stream Mapping) matrix in which the percentage of waste produced in the case study company was compared with the standard obtained from the literature review. From this analysis, a review was made of the most critical processes and the following tools were applied: FMEA (Failure Mode and Effect Analysis), SIT (Systematic Interrogation Technique), 5 WHY's and the Pareto Diagram, which allowed us to better diagnose and validate the causes.

3.3.2 Component 2: Proposed Application

This component focuses on the application of the proposed models in order to achieve or maintain a continuous improvement in the processes.

The first model is the TPM, which will focus on the efficiency and availability of the equipment to be used, ensuring reliability and reducing the problem of losses or waste (Hardt et al., 2021).

The second model is the standardized work model, which will allow the generation of homogeneous processes for the operators and their ability to generate value in the required production times (Antoniolli et al., 2017).

These models will work together with the 5S, which will ensure an incremental improvement focused on order and cleanliness, eliminating what does not generate value to the company, minimizing wasted time. For this, the management of personnel and work tools will be taken as key points for a reduction of defective products (Rodríguez & Cárcel, 2019).

3.3.3 Component 3: Implementation

In this implementation phase, for a broader and more convincing vision of what is to be achieved, a simulation of the proposal will be carried out, where the results obtained through the proposed indicators will be analyzed, taking the company's current situation as a point of reference.

3.4 Indicators

In order to evaluate the effectiveness of the integrated model implemented and to manage a quantifiable value of the results obtained, the following indicators are proposed.

3.4.1 Availability

Expresses the capacity of the machines to be available or in an active state to be able to carry out their activities normally in the manner assigned to them.

$$\frac{(Total\ hours - Stop\ hours)}{Total\ hours} * 100 \quad (1)$$

3.4.2 Percentage of Waste

Identifies the amount of shrinkage generated throughout the various production processes of any type of copper finish.

$$\frac{(Total\ amount\ of\ RM - Amount\ of\ RM\ used)}{Total\ amount\ of\ RM} * 100 \quad (2)$$

3.4.3 Overall Equipment Effectiveness

Also known as OEE, it is an indicator used to measure the productivity and efficiency of industrial machinery in production.

$$Availability * Performance * Quality \quad (3)$$

4 VALIDATION

A modeling was carried out using Arena software, taking as inputs current data from the company Metico S.A., from which probabilistic distributions were obtained in order to generate simulations (initial model and improved model) that allowed obtaining indicators that show an improvement under an ideal context. As a result, the loss rate indicator in the production process was reduced.

4.1 Initial Diagnosis

The main problem present in the entire production process is the high generation of waste, mostly due to the poor performance of the operators when carrying out their activities and the operation of certain tools and machines in the process. These activities include casting, extrusion, drawing and cutting processes. Likewise, a poor organization of the working tools was also observed, which makes manual tasks difficult and generates downtime.

4.2 Validation Design and Comparison with the Initial Diagnosis

The model was designed based on the production process of the company under study. The model starts with the reception of the batch, which will go through a series of transformation processes, as mentioned above, each process generates a certain amount of waste that accumulates approximately 7.64%.

The first component that will help to reduce this problem is preventive maintenance, which will focus on the efficiency and availability of the equipment to be used, ensuring the reliability to improve the OEE % indicator, making the use of the machines in the process more efficient. On the other hand, with the implementation of standardized work, the percentages of waste generated in the manual processes of the operators are reduced, based on the generation of homogeneous processes for the operators and the measurement of the value generated per process. As a result, a greater reduction was obtained in the cutting processes, where more waste was emitted. Likewise, the last component belonging to the 5S methodology is the Red Tag System, which also has a positive influence on the generation of waste by maintaining the order and optimal location of the work tools, which in turn reduces downtime. The management of personnel and work tools for a reduction of defective products, as well as the operation of the continuous casting machine to reduce waste in the chemical process, will be taken as key points.

In conclusion, with the implementation of the mentioned methodologies, a clear improvement in all the proposed indicators was observed, therefore, a reduction in our main problem was also observed, reaching 6.20% of the 7.64% that we had initially with respect to the indicator of the amount of shrinkage produced.

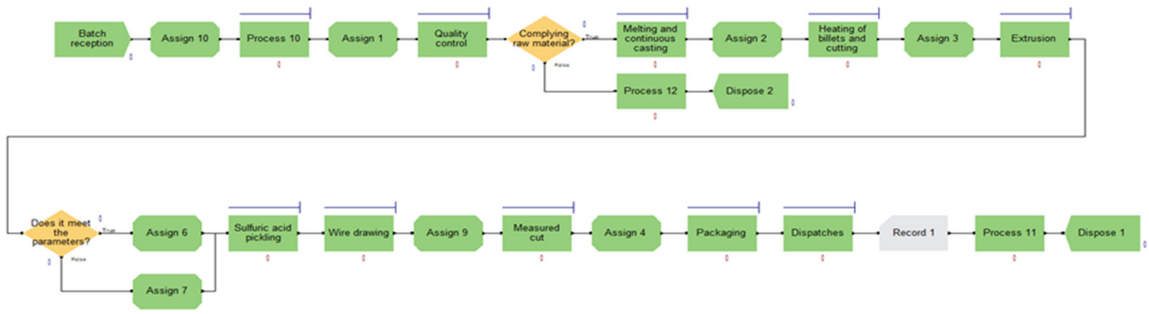

Figure 2: Proposed simulation in Arena.

Table 2: Average values of the indicators.

Identifier	Average	Half-width	Minimum	Maximum
Waste indicator (Current in kg)	175.71	6.243	161.17	184.37
Waste indicator (Improvement in Kg)	142.58	4.826	133.4	149.5
System time (Current in min)	238.63	0.13634	238	239.58
System time (Improvement in min)	230.14	0.09014	229.59	230.57

Table 3: Measurement of the project implemented

Problem	Current	Target	Improvement
High rate of wastage (production proccess)	**7.64%**	**5.24%**	**6.20%**

Table 4: Measurement of the project implemented by indicator.

Cause	Indicator	Current	Target	Improvement
Inefficient control in the casting process and in manual processes such as cutting	% OEE	**72%**	**89%**	**84%**
	% foundry waste	**3%**	**2.00%**	**2.60%**
	% cut waste	**3%**	**1.50%**	**1.80%**
Timing of measurements are not standardized	System time (min)	**239.58**	**223**	**230.57**

4.3 Improvement - Proposed Simulation

A simulation of the system was carried out using Arena software, considering a confidence level of 95% and an average error range of 10% to calculate the optimal sample size per activity. For the number of replications, 30 runs were considered for the initial model, and 55 runs were obtained for the improved model.

An increase in OEE of 7% can be seen, this was due to the TPM techniques implemented, among which the use of the maintenance cards stands out, in which a greater emphasis was placed on the cutting, extrusion and profiling tools. On the other hand, the time indicator in the system is one of the most important if we talk about productivity. This aspect was influenced by the adequate use of the 5s tool and the standardized work, which allowed the reduction in dead times, representing a reduction of approximately 9 minutes per lot produced.

5 DISCUSSION

In order to ensure greater precision of the tools applied, other production plants of the company were analyzed, these being in the same metal-mechanic industry. Using the segmentation technique, the case was divided into sub-segments related to each other by the type of manual and automated processes they handle. Within these sub-segments, similar scenarios to the main company were observed.

It is emphasized that the results obtained could be improved through an analysis involving a larger sample size. In addition, the model does not accurately cover performance improvements in automated machines, so this analysis could be improved with a chemical study of the casting techniques, with the aim of obtaining a better OEE indicator.

6 CONCLUSION

The TPM methodology was one of the tools that helped in the optimization of the machines to be used in the production process through techniques such as maintenance cards oriented to three main processes, cutting, extrusion and profiling.

On the other hand, by means of the Standardized Work tool, the activities of each operator were optimized, thus avoiding variation and standardizing the functions to be performed on a daily basis, making clear the role to be followed, preventing the risk of error in any part of the process.

Likewise, the 5S tool, which was complemented with the other tools, was the one that allowed the reduction of downtime that was witnessed during the processes to be performed, optimizing the production time and organizing the work environment.

The integration of these techniques or methodologies achieved a reduction in our main problem, which is the high rate of waste in the production process, representing a decrease of 7.64% to 6.20%, in addition, improvements are also observed in other processes such as cutting seeing a reduction of 3% to 1.80% in waste, in the OEE of 72% improved to reach 84%, in waste in the casting process from 3% to 2.60% and a reduction in time in the system from 239 to 230 minutes approximately.

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