Application of Lean Manufacturing tools to decrease non-conforming products in a zinc refinery

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Abstract

The zinc refineries present losses in daily production due to non-conforming products due to their quality, with monetary losses that are quantified in $ 3,000,000 per year and the prestige in front of their client portfolio. This occurs due to lack of controls, operational standards, and discipline in the execution of the tasks of the operators in the production lines that guarantee the quality of the zinc with a purity of 99.995%. The objective of the work carried out was to evaluate the economic losses and the reasons that cause them. An improvement action plan was designed to solve these problems under the implementation of Lean Manufacturing tools such as 5S, TPM and standardization of procedures. The development of the tools included analyzing the current state, making a diagnosis and an action plan for each system with those responsible for each area and finally measuring the effectiveness of the tools with a reduction of losses of 15% in the first year and so consecutively.

Keywords
Lean Manufacturing, 5S, standardization, procedures, zinc refinery, TPM

1. Introduction

Currently there are different methodologies to help manage and control the projects to be implemented in mining, these are included from the first phases and established in the complete cycle of these. In these moments that humanity is experiencing due to the issue of the pandemic, business competition is increasingly aggressive among them, and it is necessary to manage the final product as the stages to achieve them in the most efficient way possible (Amaral, T. G., Celestino, P. H. M., Fernandes, J. H. A., Brito, M. H. G. & Ferreira, M. B. 2012). In this context, mining projects today need to minimize their costs, increase construction productivity, satisfy the client as well as the employees and reduce losses or waste (Howell, Gregory A. 2011). The Lean philosophy is one of the management and production methodologies that helps to solve the main problems that currently have in the various manufacturing companies. Due to the above, the purpose of this chapter is to establish a research proposal that links the Lean manufacturing philosophy with the mining sector in Peru. With this, the importance of mining in Peru as in the world, the operation of a refinery and the investigations of the Lean Manufacturing implementation in various companies with its results are emphasized.

Currently, there are production losses in zinc refineries due to waste, downtime, or contamination in production lines. The main cause of this is the internal disorganization of the companies, which annually lose millions of dollars in sales and internal reprocessing.

This situation makes it necessary to develop and implement an action plan in different operational and maintenance areas in zinc refineries using the Lean Manufacturing methodology and its various management tools, to reduce or eliminate waste, downtime, and contamination in production lines.
For organizations to function effectively, they must describe and manage an endless number of activities that must be related to each other to achieve operational excellence. The activity that

uses human resources or machinery in an organization, which is used to transform a raw material into a final product, is considered a process.
A new way of managing companies is through standardized processes in production lines, these must be focused on the general objective of the organization and not individually, the main objective is to guarantee that companies have processes to:

- Eliminate operational errors
- Maximize assets
- Ensure product quality
- Facilitate work for operators

Refined zinc is a commodity product and is traded internationally. The rivalries between competitors are presented in relation to the operational excellence of their processes, since the value of the ton of zinc is imposed on the LME (London Stock Exchange) and for this reason it must be as efficient as possible in the plant operations in order to obtain the highest percentage of profit for each ton produced. It should be noted that Peru is recognized for being one of the main zinc extracting countries; As well as other minerals, it currently ranks third in the ranking of countries for having the largest zinc reserves and second in world production according to the latest “Mineral Commodity Summaries 2020” global survey by the U.S. Geological Survey (USGS), the United States Geological Survey. It should be noted that zinc, copper and gold represent half the value of exports in the country.

The first modern zinc refinery was in La Oroya, starting to produce in 1922, becoming one of the main refined zinc concentrate transformers. It should be noted that in the central Andes Mountain range the extraction of minerals began in Pre-colonial times.

The main objective of the research is to reduce non-conforming products in companies since it represents an economic loss. Achieving this first objective will improve the rate of production, the working environment among workers and the internal working conditions within them. It is expected to reduce the reprocesses of non-conforming products by 15% in the first year and so on during the first five years. It should be noted that better results can be achieved if management and the entire company are involved in the implementation of the methodology as well as its evolution in the company.

2. Literature Review

The literature reviewed for the article is based on the consequences of possible contamination in different refineries and in the zinc production process. The implementation of the Lean methodology in different companies was also reviewed, analyzing its results. According to the literature read for research on the possible impacts of contaminations on zinc refining, they indicate the following: first of all, the impact of silica in the zinc refining process, especially in the purification stage where it is extracted Cadmium is a major contaminant in the pure solution for zinc refining. (A. Janwong and K. De Wet, R. Cooper2016). It is also indicated that the removal of copper in the purification process for the refining of zinc is important because it is a polluting element and because it is a by-product for sale. Several experiments were carried out modifying various parameters such as temperature, agitation and pulp density (Sundar S. Sombhatla, Ashish Kumar, Kiran Kr. Rokkam,2019). Several studies were carried out with the residues of the leaching area, comparing Turkish and Iranian residues using sulfuric acid for the recovery of zinc, giving positive results in the investigations (Rusen, A y Topcu, MA 2018). Hazardous waste from zinc refineries containing Ag and Hg is a typical complex material obtained from oxygen pressure leaching of zinc and there are currently few economically viable methods for their disposal or reuse. The research presented here offers an effective approach for the comprehensive recovery of Zn, Fe, Cu, Ag and Hg from these highly toxic wastes for the environment as well as for the production of a high purity refined zinc (Fupeng Liu, Jinliang Wang, Chao Peng, Zhihong Liu, Benjamin P. Wilson, Mari Lundström,2019). According to studies carried out in oil refining companies such as mineral refineries in general, the implementation of Lean methodology tools improved the levels of production, quality and maintenance in them. The researched articles indicate that the implementation of tools in an oil and gas refinery in the Caribbean Sea, the study revealed a traditional approach that is currently being used in the plant, thus increasing the opportunity for hidden waste between processes, as well as lead times. Longer repairs due to faulty equipment. The results concluded that improvements were identified in the use of equipment in the plant, as well as a reduction in preparation time and hidden waste. (Alexander, A., Chowdary, B. V., & Ojha, K. 2018). The use of different tools of the Lean Manufacturing methodology for the evolution of companies in search of operational excellence. In this case, they simulated the implementation of the 5S tool in a poultry company, using the different stages to reach the goal, achieving favorable results with little effort. (Lindo-Salado-Echeverría, César, Sanz-Angulo, Pedro, De-Benito-Martín, Juan José, & Galindo-Melero, Jesús,2015). The implemented tool aims to propose a framework to guide and support a systematic approach that balances people and productivity while improving quality of life. The systematic approach, called the People-Centered Sustainable Operational Excellence Model, is described in the form of four modules that address each of the identified proposals (Bortolotti, T., Boscari, S. y Danese, P. 2015). It was analyzed that the Lean methodology can be applied to different business sectors such as clothing companies that the objective of the work investigated in the article was to design and implement an action plan for continuous improvement through the tools of Lean Manufacturing, which included 5 ' S and Visual Control. The methodology included: investigating the state of the art, diagnosing the current state, designing and implementing the action plan and the required documentation, and finally measuring the effectiveness. With the pilot implementation of this project, the times that do not add value were reduced by 12% (Marmolejo, N., Milena Mejia, A., Pérez-Vergara, I. G., Rojas, J. A. y Caro, M. 2016). Lean methodology is developed from a set of tools and techniques and can fit very well into cost leadership or cost focus competitive advantage strategies. However, maintaining competitive advantage in market circumstances is increasingly difficult with the growth of production quantity and product diversity. Therefore, the paper focuses on lean manufacturing implementation trends and issues within various manufacturing sectors. The successes and failures of Lean implementation in some industries are discussed. Lean principles were found to be a good source of competitive advantage, it is applicable to many industries, and its expansion and discussion is progressing significantly. The biggest threat in implementing lean is a lack of understanding of the concept, but those who hired consultants were more successful. (Sarria, M. P., Fonseca, G. A. y Bocanegra, C. C. 2017) (Durakovic, B., Demir, R., Abat, K., & Emek, C. 2018) (Anholon, R., & Sano, A. T. 2016)

As a result of the research carried out with different papers related to the causes of the low quality of the product in a zinc refinery, it was determined that they are mainly due to disorder, lack of operational control and procedures. Therefore, with the tools of the Lean Manufacturing methodology, you can control and create an environment of continuous improvement.

3. Methods

The implementation of three main tools of the Lean Manufacturing methodology is carried out to reduce the reprocessing of the product in a zinc refinery. The objective of the methodology is to produce correctly and with quality, when the client needs it, with a shorter lead-time and in a more efficient way.

Companies must be able to correctly perform the QCD triangle for customers, as shown in figure 1:

• Best Quality
• Appropriate price
• Just in time (JIT)

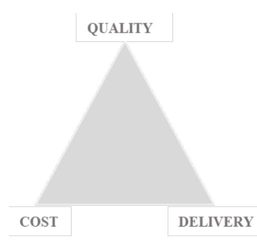

Figure 1: QCD triangle for clients

Company investors want maximum profitability without neglecting the quality of their products. Therefore, they seek operational excellence in order to satisfy their clients and investors.
The proposed model for the solution of the main problems of the company is the one shown in figure 1. This solution structure is based on the main methodology used in the research: Lean Manufacturing.
As represented in figure 2, the components that play the main roles in the proposed model are the following:

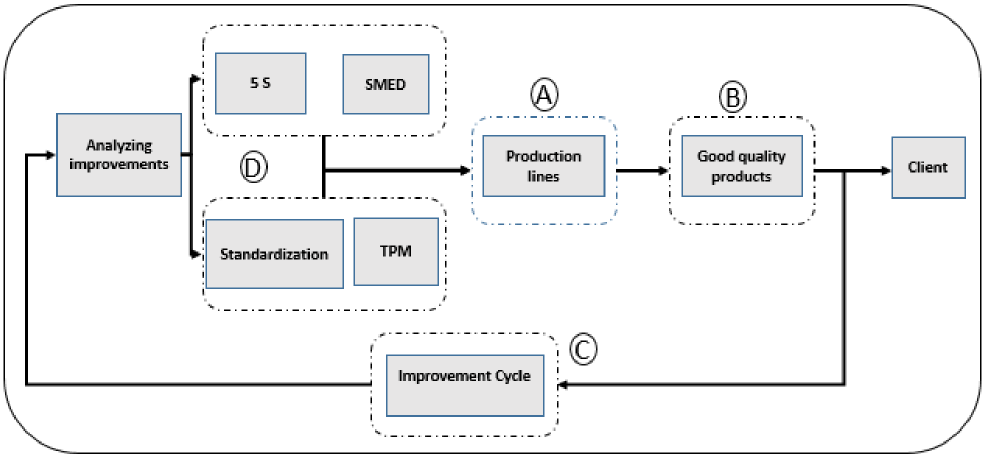

Figure 2: Main components of the implementation

• Component A

The production lines are the heart of the company and without them the product could not be manufactured to satisfy the customer.

• Component B

The products made must be of good quality and of lower production cost for the company.

• Component C

The whole process must be a continuous improvement to analyze where you can reduce downtime, reduce, or eliminate waste.

• Component D

In this component, the Lean Manufacturing tools will be used to solve the problems presented and in the improvement cycle what will be evaluated is which of the tools will be the most suitable.

4. Data Collection

Figure 3 shows the data collected for the research for the years 2017, 2018 and mid-2019 and are mainly three; the first is production data impacted by reprocessing, the second the cost of the electrical energy consumed to reprocess this non-conforming product, and the third a high consumption of equipment spare parts due to reprocessing. To validate the proposal, the history of the last three years of production of the study company was collected through the collection of information from the different software used by the company and which is recorded in the SAP to evaluate the KPIs weekly. production and product quality to review compliance with the proposed objectives. The data is collected by the supervisors on duty in each work shift with the operators assigned to the different jobs as the final control of the production volume at the end of the shift.

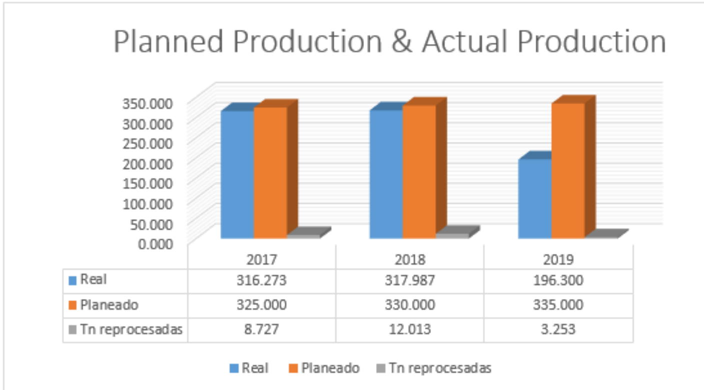

Figure 3: Production & Real Production

Figure 4 shows the cost incurred for the reprocessing of out-of-specification zinc sheets in the furnaces of the smelting area at a price of twenty-five-dollar cents per kW consumed, which must be melted into zinc dust or re-entered the process. It should be noted that zinc refineries have a high consumption of electrical energy and therefore it is a very important point to carry out the corresponding monitoring.

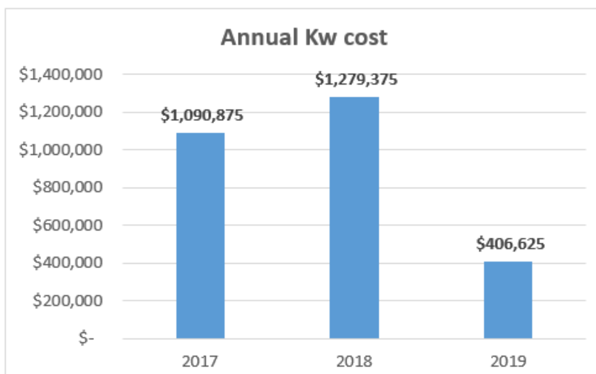

Figure 4: Annual Kw cost

5.Results and Discussion

5.1 Numerical Results

The numerical results are shown in the following tables.

The following table 1 shows month by month the total of tons reprocessed in a refinery with the total impact after three years that exceeds twenty-three thousand tons of reprocesses.

Table 1: Total of tons reprocessed

Year/Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
2017	573	473	640	518	646	1215	558	976	1127	918	670	407	8271
2018	370	473	129	208	551	206	558	1887	1679	1203	2167	2582	12013
2019	730	581	430	208	604	380	320						3253
Total	1673	1527	1199	934	1801	1801	1436	2863	2806	2121	2837	2989	23987

The following table 2 shows the hours of use to reprocess the material and the value of those Kw consumed in three furnaces with electric inductors is shown.

Table 2: hours of use to reprocess and value of those Kw consumed

Reason/Years	2017	2018	2019
Rework hours	952.67	568.61	162.94
Cost per kW consumed	$ 2,143,500	$ 1,279,375	$ 366,625

5.2 Graphical Results

The analysis was carried out in the Minitab17 system with the data obtained from the Cobalt analyzes in the pure solution (zinc sulfate) of the last three years, these samples are collected manually by operators in their work shifts. For the company, the results obtained must be within the Sigma value of factor 4 onwards. From the results obtained, none of the three years analyzed is within the requested limit to be able to obtain a refined zinc of 99.995% purity. The graphs of the analyzed data are shown below.

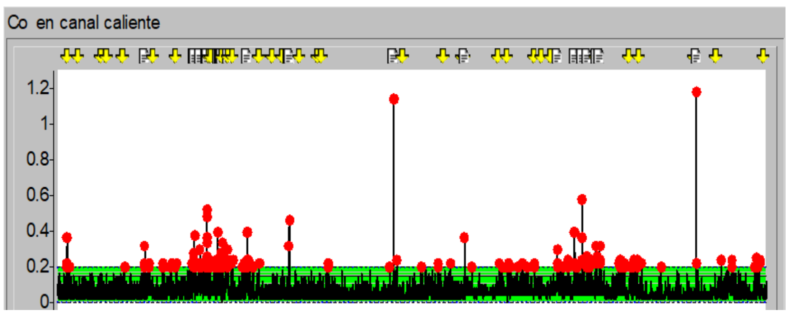

Figure 5: Analyzes in the pure solution (Zinc Sulfate)

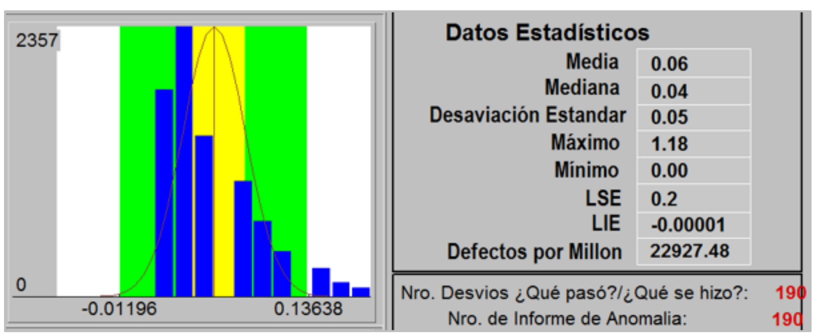

Figure 6: Process capacity

As can be seen in Figures 5 and 6, cobalt is evaluated in the hot solution channel in the purification stage. It is appreciated that it is outside the range required for the zinc process without complications in the following stages and therefore immediate action must be taken to correct the deviations.

5.3 Proposed Improvements

The implementation of the chosen tools is explained in detail below:

The 5S tool consists of several stages that must be respected as indicated in Figure 7 and having a lot of discipline in the work team as well as in the other members who participate directly or indirectly in the production process.

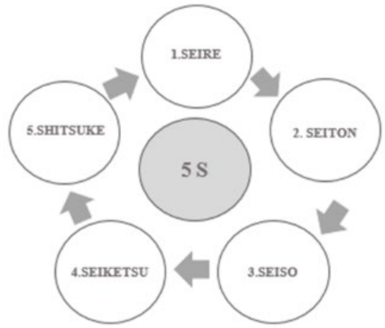

Figure 7: Tool 5s Stages

This tool will be applied in the refinery with previous training to develop a sense of ownership in the team. Then we will continue with the 5S stages, eliminating from the lines what is not useful and that takes up space, then what is necessary will be organized, such as work tools, weighing inputs to create a standardization with all collaborators and finally constant internal audits to continue improving day by day.

In the standardization tool, meetings with the workers will be implemented in the different shifts in order to capture the best work practices of each of them. Then the process area will review those meeting to apply them in procedures that could be useful for the company. When these are already validated at the different levels, training will be carried out with the workers with close monitoring to ensure that those best practices are met and thus be able to analyze the results to continue improving. In this way, it will be an important pillar to reduce low production as indicated in Figure 8.

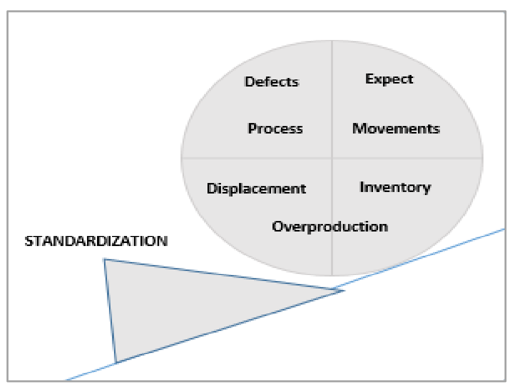

Figure 8: Standardization Tool

The implementation of the TPM will be developed by creating small working groups between maintainers and operators to increase their knowledge and skills, so as to create a management focused on continuous improvement and autonomous maintenance of the production lines as well as the maintenance of the equipment. All this will happen through continuous training and inspections at work.

5.4 Validation

Next, figure 9 explains the contribution model as the different stages of diagnosis of the problem (phase 0), after the implementation (phase 1) which is the use of the selected tools and to finish the verification is carried out (phase 2) which will be the last phase that will tell us if the methodology is working or should be adjusted to achieve the determined objective.

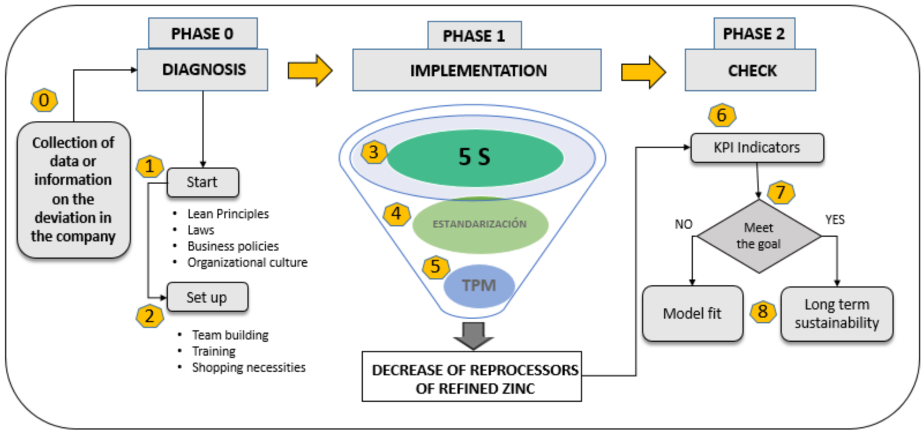

Figure 9: Proposed Model Method

The performance indicators also called KPI (Key Performance Indicators) are used to measure the behavior of the implementations carried out in the company, in a way that allows to achieve the objectives and goals set from the beginning of the implementation. The indicators to follow in the investigation are the following:

1. Quality of products

The main thing for a company is the quality of its products, therefore, the main indicator after the implementation of the tools is to comply with quality standards.

2. Audit observations

Audits are an important point after any implementation, as it will be the way to individually check if the tools are working correctly in the system.

• 5S

The indicator to be measured in this tool will be indicated in figure 9 and consists of monthly inspections with the team leader and the operators.

$$\frac{Number\ of\ activities\ converted}{Total\ activities} \times 100 \qquad (1)$$

• Standardization

In the standardization tool, the indicator will reflect the percentage of procedures carried out by the work team. In this case, the goal to be achieved must be indicated, in order to measure the productivity of the team, including the training and safety area. Figure 10 shows how to calculate it.

$$\frac{Number\ of\ procedures}{Total\ activities} \times 100 \qquad (2)$$

Also, in this tool, the training should be monitored so as to allow workers to apply the procedures in the lines of production. Figure 11 shows how the training area will be measured.

$$\frac{Number\ of\ trained\ procedures}{Total\ number\ of\ procedures} \times 100 \qquad (3)$$

The model proposed for the research is the use of the Lean Manufacturing methodology with its respective tools. This model is based on the various investigations carried out and on interviews with experts in the field, to implement the most suitable tool.

For the implementation of the proposed model of this research, the times that the world is currently living in due to the issue of the COVID-19 virus were taken into account. The first tool used in the process is 5S which is explained in Figure 9, the work teams will be grouped for the corresponding training and the future execution of the five stages.
Figure 10 explains the implementation of the procedure standardization tool, which is key to guaranteeing product quality.

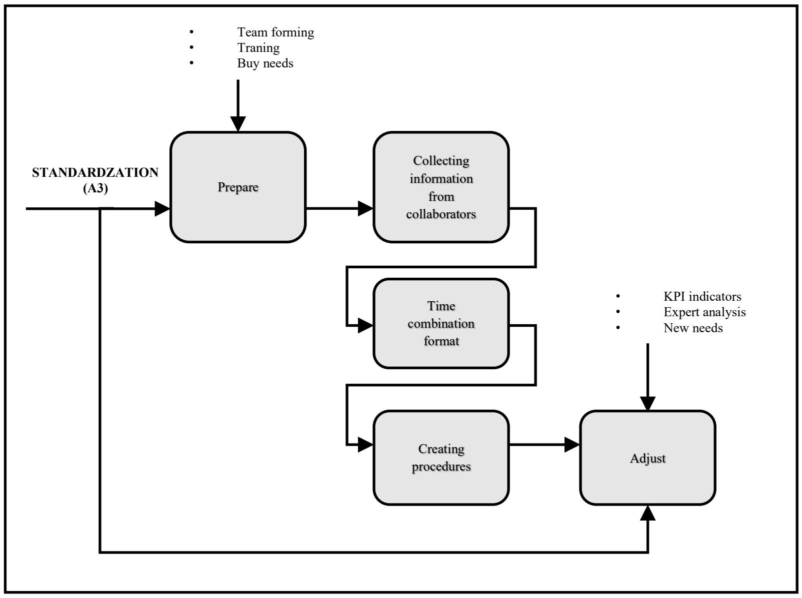

Figure 10: Procedure Standardization Tool

Figure 11 indicates the TPM implementation. Only two stages were chosen for the research: autonomous maintenance and focused improvements, as we focus on the execution of the operators.

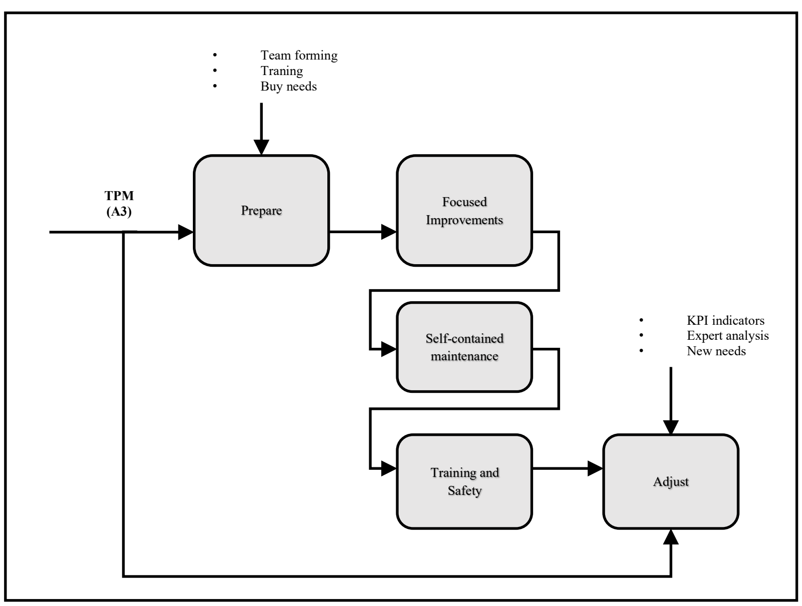

Figure 11: TPM Implementation

The Arena software was applied to simulate the process without improvement Figure 12 and the process with improvement Figure 13.

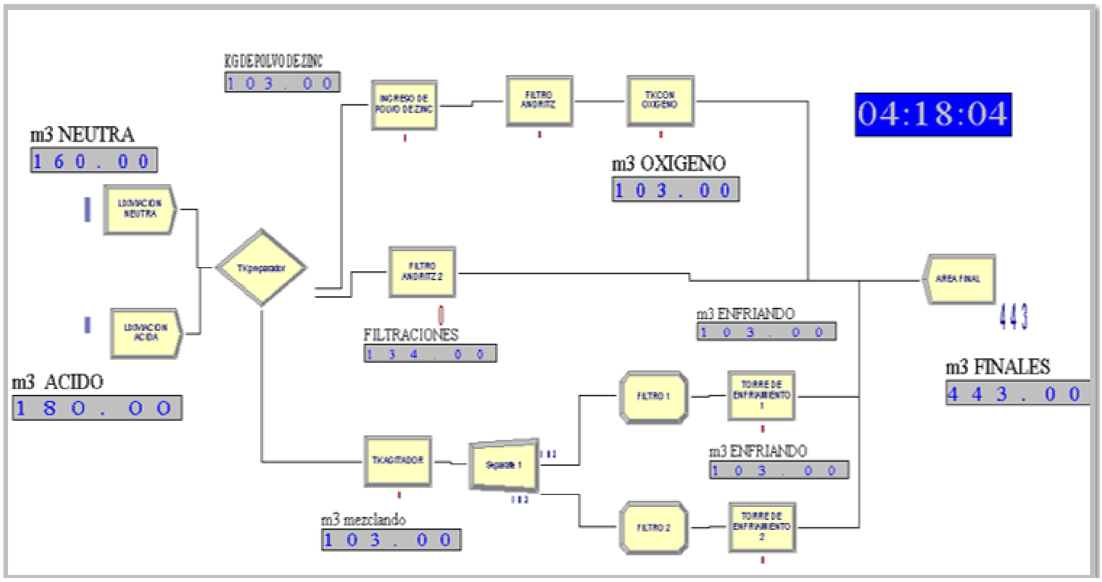

Figure 12: Simulation of the current situation

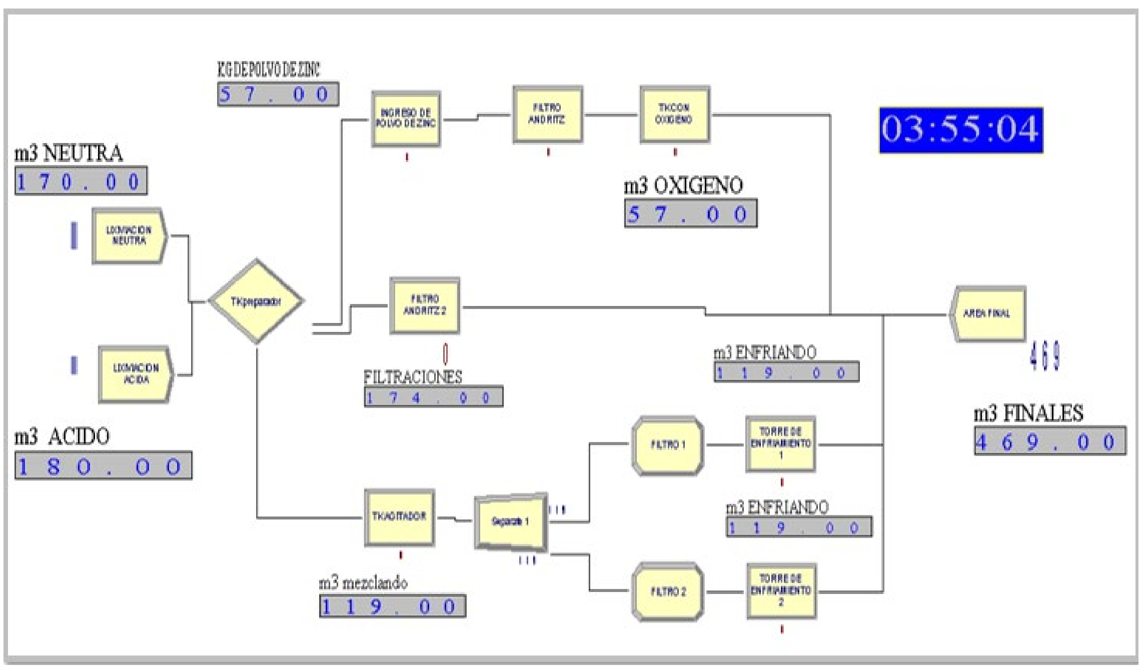

Figure 13: Simulation of the Improved Situation

The results obtained after the application of the various tools are shown in Table 3.

Table 3: Results obtained

Data Production	Before	After
Time	4:18:04	3:55:04
Final production	433 m^3	469 m^3
Zinc powder consumed	130 Kg	57 Kg
Neutral soluccion consumed	160 m^3	170 m^3
Acid soluccion consumed	180 m^3	180 m^3
Number of leaks	134	174

During the simulation, it was found that the production time, the amount, the zinc dust consumption, and the number of filtrations were improved to purify

6. Conclusion

With the implementation of the Lean Manufacturing methodology, it is expected to reduce non-conforming products for sale in the first year from 15 to 25% and so on during the following years. This is due to the implementation process and commitment of the entire company to do so. An improvement in the work environment is estimated by more than 10 points on the scale as a reduction in the number of employees leaving the company.

The results obtained were a decrease in reprocessing in the first 3 months of 5% of the lost production. The equivalent of 5% is 1,199 tons of zinc added to the final production for sale. After implementation with the recovery results obtained, they represent a total return of approximately $ 2,999,500 for the refineries. It was found that the 5 S tool has an efficiency in the recovery of the lost tons of 34%. The standardization tool participated in the recovery of the lost tons of 58%, this tool is the one that most apport to achieve the objective. It was found that the TPM tool had an efficiency in the recovery of the lost tons of 8%, since it supposes that this tool is slower for the implementation. The work teams were complemented and involved to achieve the objectives of the implementation proposal, improving the work environment by 2%.

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Biographies

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Iván De Fuentes-Pérez is an Industrial Engineer from the University of Applied Sciences of Peru with 20 years of experience in the industrial maintenance sector and mechanical projects for the mining sector in Europe and South America. He has extensive experience in maintenance management, implementation of industrial safety programs, development of continuous improvement programs, alignment of maintenance plans using RCM methodology, implementation of autonomous maintenance and TPM. My work is carried out in mining companies in Peru and Brazil developing equipment for the production of zinc such as cranes, zinc delimitators, cooling towers and anode cleaning machines.