Production Model to increase OEE through the application of Lean Manufacturing and Total Production Maintenance tools in animal feed manufacturing SMEs

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Abstract
This research proposes a production model capable of increasing the Overall Equipment Effectiveness (OEE) using the methodology Lean Manufacturing and TPM. The case study is a company in the livestock industry where the 4 phases of the model were implemented. The first phase is the implementation of the Poka-Yoke tool. Then follows the implementation of the MRP. After that, the implementation of a preventive maintenance plan, and the last phase is implementing the 5S tool. After validation in the Arena software and the simulation of the implemented production model, it is shown that the OEE indicator increases by 15.69%, managing to achieve a productivity improvement.

Keywords
OEE, Lean Manufacturing, MRP, Production Model, 5S, and TPM.

1. Introduction
The growth of the livestock sector in Latin America has risen by 3.7% per year. This is because the demands for both beef and poultry meats have risen in recent times, according to the Food and Agriculture Organization of the United Nations (2022). In Peru, in 2021, the livestock industry has reached a production of 383 thousand tons. Of which, 33.1% comes from poultry meat and 10.9% from the production of chicken eggs.

According to the Ministry of Production (2022) an advance was registered in the operational development in the production of meat products due to the increase in local consumption and to satisfy the demand. 60% of the technologies for the development and planning of operations are multifunctional. These help in decision making in the operational management of the PYMES (Technological Institute of Production 2021). As evidenced, the use of engineering tools alongside the technology is vital for the competitiveness of a company nowadays. Thus, the absence of operational development and efficient production models is a significant problem that negatively and dramatically affects the profitability of an organization. Being this way, the implementation of indicators that measure the performance of production models is very relevant. The overall equipment effectiveness (OEE) is a standard to measure productivity (Soltanali 2021).

The purpose of the study presented by Tylor et al. (2022) is to optimize a production system. The collected information allows businesses to introduce a critical threshold production policy based on corrective and preventative maintenance strategies and sampling-based quality control. Finally, an analysis was run to guarantee the concept's viability. On the other hand, García et al. (2022) is a case study that remarks on the importance of maintaining the OEE optimal level that corresponds. The use of tools from Lean Manufacturing avoids waste generation and reprocessing in a way that helps to reduce the environmental impact and increase the economic benefits. This study confirms that the use of tools from Lean Manufacturing, like the 5´s, Poka Yoke and the Preventive Maintenance, are going to help increase the OEE indicator and the company profitability.

Therefore, the reason for this research is to develop and validate, using the Arena simulator, the effectiveness of a production model, with a focus on Lean Manufacturing and MRP that allows to improve the OEE level and, with it, increase profitability. This research will be divided into six parts, which are Introduction, Literary Review, Data Collection, Results and Discussion, and Conclusion.

1.1 Objective

- Propose a production model on the basis of Lean Manufacturing and TPM tools that allow to increase the value of the OEE indicator.
- Promote the operational development of control and planning of resources using Poka Yoke and MRP tools.
- Reduce downtime due to unplanned and planned stops using the 5S tool and create a preventive maintenance plan.
- Validate the proposal and analyze the solution model's results on the Arena software.

2. Literature Review

2.1 Planning and production control

Production settings have become less predictable and more variable; consequently, delivery time and a high rate of client satisfaction have become essential in this new context. The Production Planning and Control (PPC) processes have to be integrated with the objectives of the manufacturers (Quispe et al. 2022). The supply chain's risks are considered a substantial obstacle to achieving the current supply chain management processes successfully. The increasing complexity of the commercial operations brings a series of risks to the supply chain, negatively affecting a company's performance (Saleem 2020). The importance of performing quality orders, meeting delivery orders on time and avoiding penalizations for even losing clients has made an economic impact on the late deliveries. Therefore, the application of material planning manages to mitigate the problems in the production line in a way that the delivery time of products is reduced (Casallo et al. 2021). A clear example is the study of the manufacturing company called Dynaplast, which has demand fulfillment problems and overproduction. For this reason, an investigation by the company's department was made to make an aggregated planning, capacity planning, material requirements planning and capacity needs planning. This allowed us to determine the deficiency and improvements to apply (Gunawan et al. 2021).

2.2 MRP

Demand Driven Material Requirements Planning (DDMRP) is a viable and recent material management technique which has been implemented in business. DDMRP recommends a fundamental re - evaluation of the logic underlying MRP. By combining elements from Lean Systems and the Restrictions Theory and implementing new elements such as dynamic buffers, DDMRP adjusts the fundamental logic of MRP to better meet customer demand in an environment that is more demanding, turbulent, and dynamic. Companies have acknowledged that the DDMRP is the best planning strategy. This work introduces and investigates DDMRP. In addition, using a series of structured computer simulation studies, we evaluate its efficacy in comparison with two generally acknowledged approaches: MRP and Kanban/Lean manufacturing. The results clearly demonstrate that DDMRP is a superior method that merits additional research (Miclo 2019).

2.3 Preventive Maintenance

The production is supported by a variety of machineries and pieces of equipment that work cooperatively to achieve maximum efficiency. Owing to the need for the operator to replace the harmed machine pieces, the corrective maintenance system, which is intended to repair or replace the machine's components after a failure, results in delayed production time. Loss of production time can result in missed production goals, resulting in a significant cost of loss. All of the components are extremely expensive. This is why preventive maintenance, or programming engine components to optimize maintenance efficiency, is required. Reliability Engineering and Maintenance Value Stream Mapping are employed (MVSM). Using preventive maintenance enhances the efficiency of maintenance by an average of 16% (Sembiring et al. 2018). The modification of maintenance plan by converting unscheduled activities into planned interventions that can be carried out at a predetermined time before a component failure, be able to reduce operating and maintenance costs (Koukoura et al. 2021). The optimization of corrective maintenance can generate savings that can mitigate costs related to production losses, such as the extension of the asset life cycle. The case study proposed by these authors has the purpose of applying preventive maintenance actions and predicting possible flaws (Abbate et al. 2022).

2.4 Lean Techniques (5S / Poka - Yoke)

Lean concepts are essential to optimize production and minimizing waste. Profitability can be increased through the effective usage of Lean Techniques (LT). The four KPI (Key Performance Indicators) which are kept for analysis are Work in Progress, Cycle Times, Production Yield, and Number Of defects. The results demonstrated that Poka-Yoke and 5S LT are applicable in any industrial setting. The goal of the study conducted by Kryuchkova (2022) is to demonstrate that the implementation of the 5S technique assures the order of the availability of resources, reduces reprocessing for defective work, and increases worker productivity.

2.5 Poka-Yoke

The many Lean tools have a substantial effect on reducing defects, as well as cycle time and costs. According to research conducted by Amrani y Ducq (2020), The defective rate was reduced by 66%, the cycle time was reduced by 43%, waste disposal was accomplished, and the Work In Progress (WIP) stock was reduced. In addition, a 50 percent reduction in trucking expenses was demonstrated as a result of applying Lean Manufacturing. Finally assists in expanding lean ideas by providing proof of concept.

Poka-Yoke (PY) has been utilized for many years as a method for overcoming the difficulties that process mistakes and flaws might cause. It is a widely established concept and method of thinking that has contributed significantly to the fight against the incidence of errors in many work processes. In addition, research conducted in a manufacturing firm reveals that the application of Lean Manufacturing techniques, such as Poka-Yoke, increases productivity by 8 to 12 percent by reducing defective goods, unproductive times, and unexpected machine stops (Carranza et al. 2021).

Companies in Peru presenting obstacles for low efficiency due to a large proportion of production losses. A study conducted in a Peruvian manufacturing company intends to use the Poka-Yoke model in a way that demonstrates a 24 percent boost in productivity and the elimination of reprocessing processes (Roca et al. 2021)

2.6 Overall Equipment Effectiveness

The implementation of Overall Equipment Effectiveness (OEE) has proven to be extremely advantageous for growing equipment availability, performance rate, and quality rate, while reducing unscheduled equipment breakdowns and waste (Kumar et al. 2015). In order to increase food industry productivity, production performance measurement is the most essential activity. Overall Equipment Effectiveness (OEE) is a measurement benchmark for industrial productivity (Soltanali 2021). The research paper written for a corporation in the food industry that examines four markers of efficacy is a prime example. That is, mean time to failure, mean time between failures, mean time to repair, and equipment efficacy overall. This study aims to discover the correct usage of the indicators for a correct interpretation of the data, which will lead to greater productivity (Daniewski et al. 2018).

3. Methods

This scientific article will study the case of a company dedicated to the Production of Feed for Animals that shows problems in the level of its operating performance. The focus of this research will be both qualitative and quantitative, that is, of a mixed type because numerical measurements, data collection and frequencies will be taken into account, as well as interviews with people specialized in the subject of study.

To begin with, a general diagnostic of the entire company and the different areas was carried out to find the main problem that is affecting the performance level. It was identified that the Overall Equipment Effectiveness (OEE) is 36.61%, which indicates there is a gap of 48.39% with respect to the ideal (85%). According to Díaz Contreras et al. (2020), "the OEE prevents individual sub-optimization of machines or production lines, providing a systematic method of stabilizing production targets and incorporating practical technical management tools in order to achieve a balanced view of process availability, quality, and performance." This indicates that having an adequate level with this indicator would even reduce high costs that affect the companies.

Therefore, when analyzing each element that includes this indicator, low performance of 68.75% is obtained due to reactive maintenance stops, lack of material planning as raw material and supplies, and the accessibility conditions of the primary material. On the other hand, the low availability of equipment is being affected with 36.61%. This is due to excessive downtime at unplanned and planned stops. Finally, a low quality of 77.54% is seen, which is caused by

the increase in returns for not meeting the maximum humidity levels and poor coding procedures. However, for this case study, the performance integration and the equipment availability will be analyzed.
A model was developed to identify the problem, and the effects, and mainly determine the root causes that are affecting the development of the case study, as shown in Figure 1.

3.1 Model Proposal

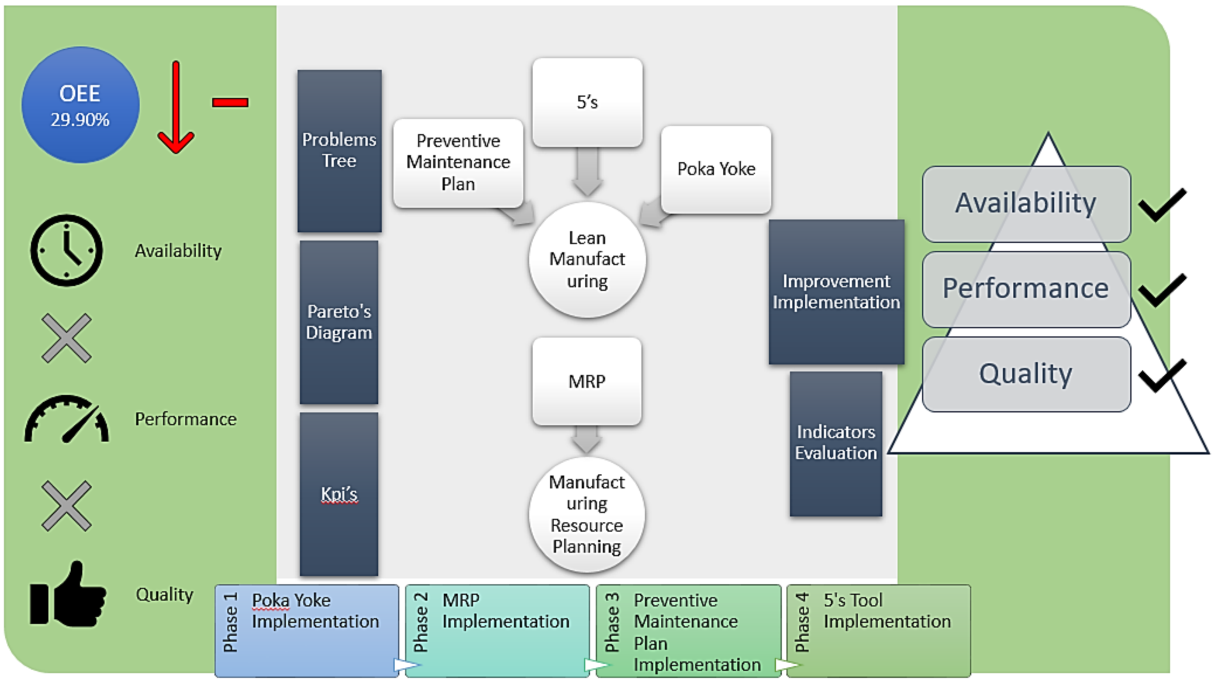

Figure 1. Proposed Model

Figure 2 shows the development, planning, and implementation of the proposed model can be visualized in detail. It was worked with the Bizagi Modeler software for a better understanding of the process stages.

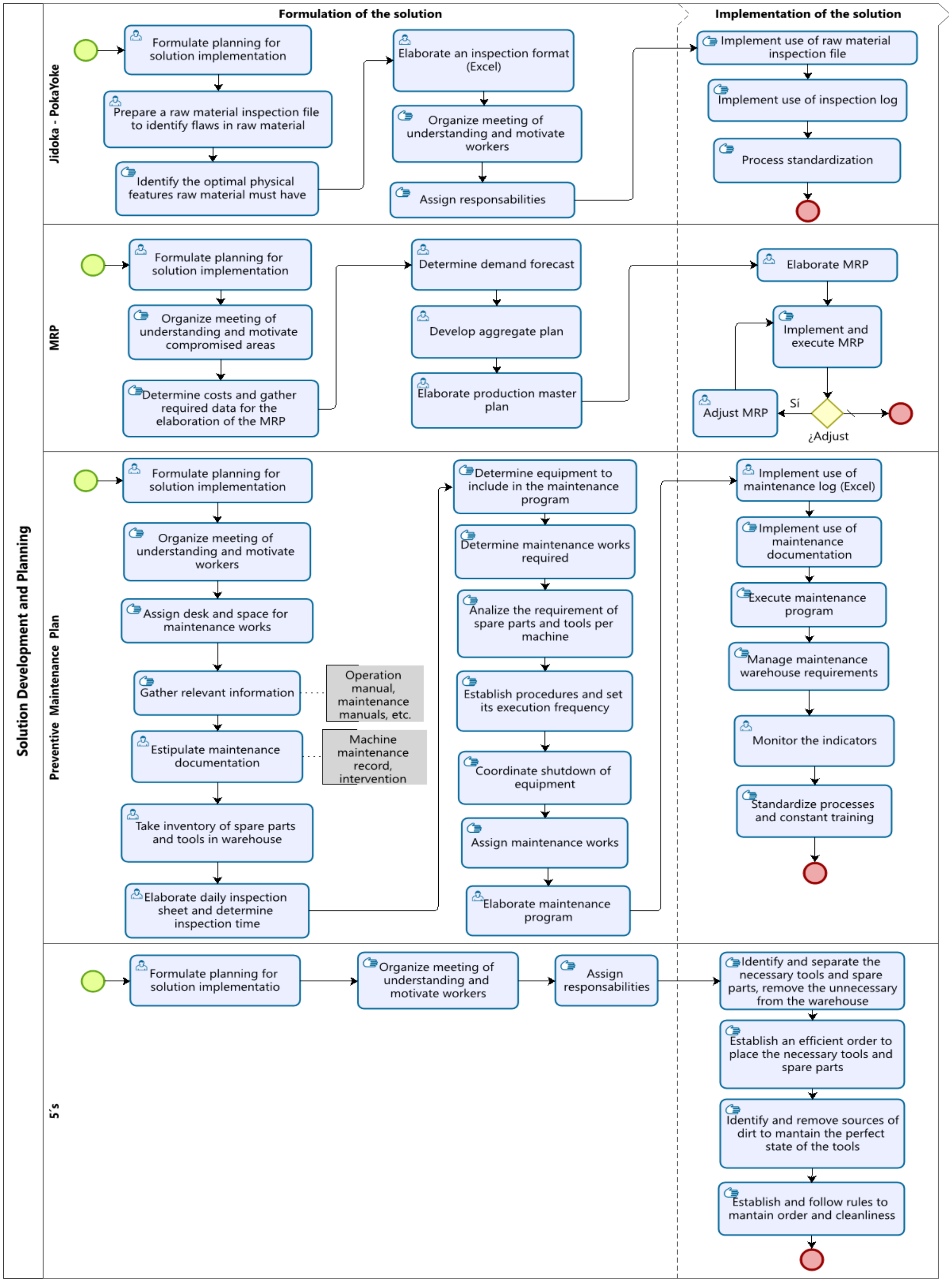

Figure 2. Development, planning and implementation of solutions

4. Data Collection

For the data collection, various information gathering tools were used. Guided visits to the plant were scheduled, in the same way the plant personnel were surveyed, and the plant manager and the manager were interviewed. Finally, information validation meetings by company personnel were held. All the information gathered will allow us to correctly evaluate the scenarios. The Pareto and Ishikawa diagrams, being fundamental tools, were very effective in identifying the main problems. In the same way, root-cause diagrams were used to accurately determine the effects of the problems found. Figure 3 shows the flow of activities carried out to obtain the results.

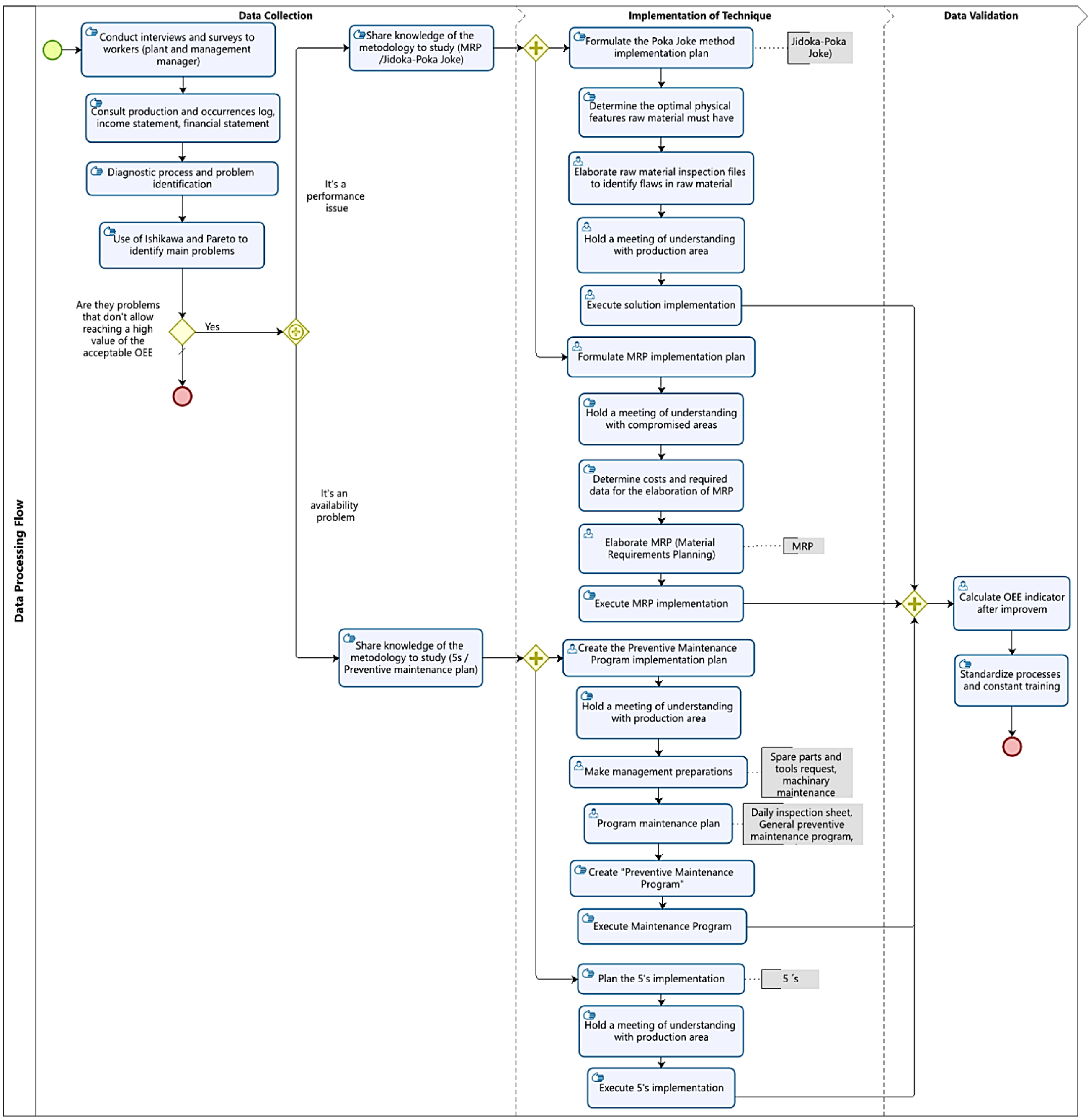

Figure 3. Data processing Flow

5. Results and Discussion

5.1 Numerical Results

Table 1 shows in detail the calculation of the OEE (Overall Equipment Effectiveness) coefficient is shown in detail. In the first place, in the Performance indicator, the goal is to reach more than 95%; however, the company presents a performance of 68.75%, which indicates the performance is low. In the same way, the equipment availability is optimal when the value is greater than 90%; however, it is 56.10%, below the ideal, so it is necessary to apply maintenance measures to improve the indicator. Finally, with respect to quality, it shows the same behavior as the other two indicators. The goal is to reach a quality greater than 99%; however, it stands at 77.54%. Even though it is one of its best indicators, it is not optimal yet. For this opportunity, work will be done to analyze the most critical indicators. In this case, they are Performance and Availability.

Table 1. OEE of the current situation

Indicator	Goal	Metrics	As Is Value	Conclusion
Performance	> 95%	$\frac{\text{Actual monthly production}}{\text{Programmed monthly production}}\ x\ 100$	68,75%	Productivity lower than goal. Requires measures
Quality	> 99%	$\frac{\text{Perfect orders}}{\text{Total orders}}\ x\ 100$	77,54%	Indicator is lower than established goal, requires measures
Availability	90%	$\frac{\text{T. Available} - \text{React. Mnt.} - \text{Planned Mnt.}}{\text{T. Available} - \text{React. Mnt.}}\ x\ 100$	56.10%	Value is too far from the goal, requires measures
Overall Equipment Effectiveness	85%	Performance x Quality x Availability	29,90%	Value reached is too far from the goal set, requires measures

The performance of previous years was analyzed with respect to the annual schedule production for each year. Table 2 shows that the percentage of yield per year is falling, which indicates that the methods applied are not correct and they are affecting the yield of production.

Table 2. Performance appraisal per year

Description	2018	2019	2020
Total Annual Production (Tn)	11255	10979	10725
Programmed Annual (Tn)	15200	15400	15600
Performance	74.05%	71.29%	68.75%

Some causes that stopped producing due to low performance with respect to the number of tons that stopped producing for different reasons were determined. Firstly, there is a 50.16% for maintenance problems, which is shown in the graphic it is the cause possessing the highest percentage, affecting more the company performance on the productive part. Secondly, there is the lack of raw material and supplies, which generates a 29.96% of the low performance because of the poor management of these. Lastly, the crusher clogging due to very large stones represents a lower percentage of 19.88%, which makes visible how this cause affects the indicator.

When studying the Availability indicator, the crucial elements that compose it were analyzed to give an accurate result. Table 3 shows the Mean Time to Repair (MTTR), as well as the Mean Time Between Failures (MTBF). In this way, it was possible to support the low availability of the equipment.

Table 3. Equipment availability assessment

MTTR	3.54
MTBF	4.523
Availability	56.10%

Numerical calculations have also been made to obtain the current maintenance cost, without implementing preventive maintenance and without applying the 5S, which are detailed in Table 4.

Table 4. Maintenance cost without solution

Description	Hours	Costs (PEN)
Reactive Maintenance Man-Hours	1340	11,390
Spare Parts and Materials		9,820
		21,210

Finally, the calculation of the cost of the poor planning of operations was made, since all production stops must be compensated with overtime to meet the monthly demand. The total cost is shown in detail in Table 5.

Table 5. Cost of poor operations planning

Rate	Monthly sales (Tn)	Init. Inventory (Tn)	Aver. Monthly Prod. (Tn)	Final Inventory (Tn)	Storage Cost (PEN)	Extra Hours	Total Cost (PEN)
0.08	881.00	0.00	830.52	0.00		21.95	329
0.08	882.12	0.00	830.52	0.00		22.43	337
0.09	971.45	0.00	830.52	0.00		61.27	919
0.07	837.45	0.00	830.52	0.00		3.01	45
0.08	904.45	0.00	830.52	0.00		32.14	482
0.07	770.46	0.00	830.52	60.06	90	0.00	-
0.07	781.62	60.06	830.52	108.96	162	0.00	-
0.06	703.46	108.96	830.52	236.02	352	0.00	-
0.14	1548.73	236.02	830.52	0.00		209.65	3,145
0.08	937.95	0.00	830.52	0.00		46.71	701
0.09	974.33	0.00	830.52	0.00		62.53	938
0.09	990.54	0.00	830.52	0.00		69.57	1,043
Total					**604**		**7,939**

5.2 Graphical Results

In Figure 4, the current simulation model worked on the Arena software is shown. In this figure, a red box indicates the parts of the process where the improvements will be implemented. While in Figure 5, the simulation model, with the proposed production model implemented, is shown.

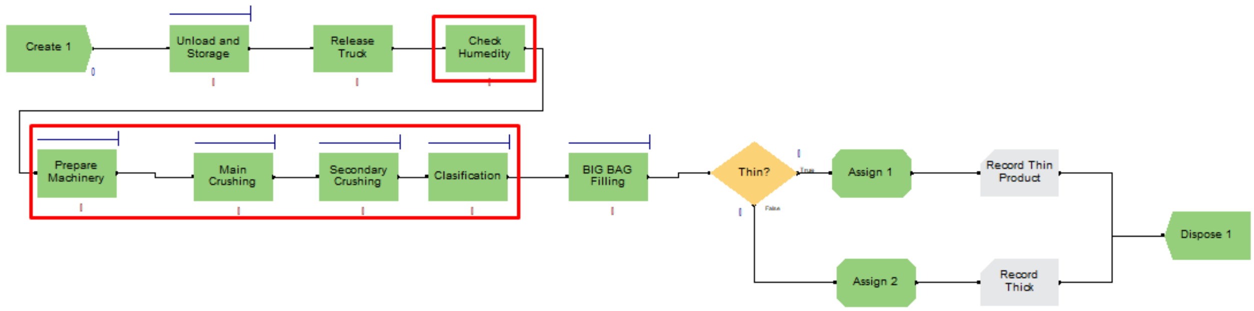

Figure 4. Model of the current situation

The fourth activity "Check humedity" in figure 4 consists of a quick visual review, this has been replaced by the inspection format as part of the implementation of the proposed improvements. Therefore, the activity is now called "Execute inspection" which refers to a planned and more detailed inspection.

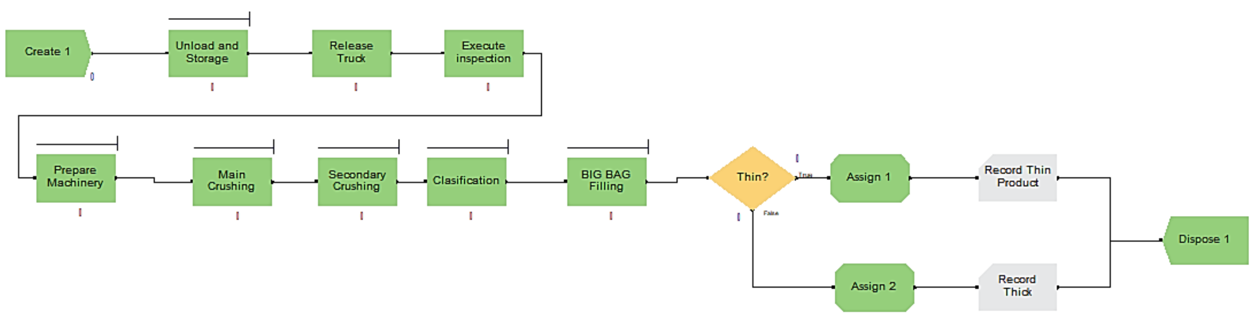

Figure 5. Model with proposal implemented

5.3 Proposed Improvements

Once gathered the information and all the calculations previously shown were made, we will proceed to the process simulation. The process simulation on the Arena software is a critical stage of the investigation, because this will allow us to analyze the current situation of the production process of the company. The most important goal of the simulation is being able to visualize in the generated report the percentage of use of the machinery and the amount of merchandise produced, etc., because these indicators will show us the impact of the proposal of the production model being proposed in this research.

According to Aregawi et al. (2017), the analysis process, using a simulation by means, can be used to model the different procedures existing in the companies. This process can quantify the efficiency of procedures, workplace layout, resource management, machinery utilization, operator efficiency, production cost, and processing times.

In the model shown in figure 4, elaborated on the Arena software, the current and real operational processes to simulate are detailed through a flowchart. Once the simulation was executed and its report was generated, we analyzed the data and checked that the daily production of finished product on average is 17 big bags of thin product and 12 big bags of thick product. Another data from the report, and it is very important to highlight, is the average utilization percentage of the machines. This were 46.75% the crusher, 56.75% the mil, 34.08% the forklift, and 40.25% the vibratory sieve.

To improve the availability, the performance, and, with it, the OEE indicator, it was implemented, in the first phase, an inspection sheet to identify the optimal batch of raw material and make a record of these. In the second phase, to implement an MRP, the demand forecast was determined so we could prepare the aggregate production plan. Then, the production master plan was created, so we could establish a pre-analysis of the resource's quantity and the required time. Because of this, this tool allows having a material requirement planning much more adequate and precise. In the third phase, a preventive maintenance plan was implemented, taking into account the life sheet of the machines, maintenance orders, inspection sheets, etc., to improve the equipment availability and don't have unplanned stops in production. Lastly, in the fourth phase, the 5S tool was implemented to improve productivity and efficiency in work environments.

The Arena software simulation of a manufacturing company was executed, using 12 effective hours per day and 100 iterations, having a scoop in each one of the productive area's scoops (crushing, grinding, classification, and bagging). As a result, an average production of finished product of 22 big bags of thin product and 16 big bags of thick product was obtained. Also, from the generated report, we obtained the following percentages of use of the machines. This were 66.40% the crusher, 70.32% the mil, 51.03%% the forklift, and 57.28% the vibratory sieve.

Comparing the simulated results in Arena. The increase in daily production can be seen: 5 more tons of fine product and 4 more tons of thick product. In addition, the results indicate an increase of 16.8% on average in average utilization percentage of the machines.

5.4 Validation

In other similar research, where they apply the same tools and engineering methods that are being applied to the production model proposed in this investigation with the objective of improving the OEE and, with this, the productivity, profitability, efficiency and effectiveness of processes, they indicate the efficiency of maintenance increases due to the preventive maintenance by an average of 16% (Sembiring et al. 2018). In addition, the research published by Carranza et al. (2021) indicates that productivity improves from 8 to 12% applying Lean Manufacturing tools, such as Poka-Yoke, to reduce defective products, unproductive times and the unplanned machine stops. Lastly, Pooya and Pakadman (2019) conducted research about the effectiveness of MRP with an approach based on an industrial environment, managing to validate and affirm the effectiveness of this method, that has a significant impact on the supply chain and, with it, on the productivity and profitability of the operations.

In the final scenario, with the implementation of the proposed production model, we have improved performance, going from average daily production of 29 tons to 38 tons of average daily production. This represents 31.04% with respect to the initial situation. The percentages of use of the machines also increased, as shown previously. With this, the availability increased from 56.10% to 73.62% and the performance went from 68.75% to 79.86%. Lastly, the OEE indicator went from initially 29.90% to 45.59% with the implementation of the proposed production model.

6. Conclusions

It is concluded that the production model proposed in this investigation will increase the Overall Equipment Effectiveness indicator by 15.69% with respect to the AS IS. This result is due to the operational development and the implementation of the lean Manufacturing tools and TPM in four phases. The first phase is the implementation of the Poka-Yoke tool. The second phase the implementation of the MRP. The third phase is the implementation of a preventive maintenance plan. The last phase is the implementation of the 5S tool. Likewise, as a consequence of the increase in productivity, the profitability will also increase.

This investigation is validated by creating a model and simulating the procedures using the Arena software. Checking that Lean Manufacturing techniques are applicable and effective to increase the Overall Equipment Effectiveness in the different contexts and industrial sectors. This way, the proposed production model will contribute and demonstrate that using Lean Manufacturing methodology, TPM, and the OEE indicator will improve the effectiveness of the operations and reduce the downtime times in this type of industry.

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