Production Model Based on Total Productive Maintenance and Systematic Layout Planning to Increase Productivity in the Metalworking Industry

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***Abstract*—The metalworking industry represents one of the most critical factors for the economic development of each country. However, one of its significant bottlenecks is prioritizing some orders over others and the late Maintenance of machinery, which generates stoppages in production lines and delays in processes, which translates into decreased plant productivity. Therefore, to solve these problems, this article proposes a production model based on Total Productive Maintenance and Systematic Layout Planning, which focuses on machinery and human resources to increase the Productivity of companies in this sector. The model simulation was carried out using the Arena software, where a 7.69% improvement in Productivity was obtained and a reduction of up to 32 days in the cycle time. This improvement proposal allows companies in the sector to be more competitive and provides the necessary tools to optimize their processes.**

***Index Terms*—Total productive maintenance, systematic layout planning, productivity, metalworking**

I. Introduction

Over the years, the metalworking sector has become one of the main economic activities in the world since it has excellent potential to generate wealth, well-being, and employment. This industry constitutes a fundamental link in a country's production, not only because of its technology and added value but also because of its articulation with different sectors in the industry (Alandete and Barahona *et al.*, 2021). Thus, this sector is vital, so optimizing its processes is extremely important.

Wiyaratn and Watanapa (2010) claims that plant design can help reduce manufacturing costs and increase production. Industrial design planning using the Systematic Layout Planning (SLP) tool can improve the production process flow by optimizing the plant and making good use of space. Likewise, the Total Productive Maintenance (TPM) tool focuses on improving the effectiveness of the equipment and maximizing its production. It seeks to maintain the optimal conditions of the equipment to avoid breakdowns, speed losses, and defects in the quality of the products and the process. This tool encourages the participation of operators and performs preventive maintenance activities (Chand and Shirvani, 2000).

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A comparative study of 3 companies in the metalworking sector confirmed that the main aspects of improvement are: Maintenance, analysis of the production route and material handling, and production planning. An improvement of these points would contribute to the progress of the production area since it would allow it to operate efficiently and prevent future changes; all this added to a considerable increase in Productivity (Terán and Sanchéz *et al.*, 2009).

To improve the Productivity of companies in the metalworking sector, it is necessary to start looking for an improvement in the quality of processes and customer satisfaction. It happens because more than good management of productive resources (labor, machinery, and raw materials) is required every day, even more so in a competitive industry in the national and world market (Kojima and Lemos, 2016).

II. State of the Art

A. Production Management in the Industry

A study of Ahuja and Khamba (2008) in the metalworking sector shows how applying TPM resulted in the establishment of proactive Maintenance and the development of its competitiveness in the industry. Furthermore, a key concern is producing various high-quality products and reducing production times and costs (Patil and Kuber, Kuber). Sutari and Rao (2014) reveals that plant layout optimization is crucial to making the industry more efficient and demonstrates the importance of implementing SLP to improve Productivity and optimize plant space.

Implementing TPM improves the productive processes of a company in the metalworking sector since it increases maintenance efficiency as a strategic factor and, consequently, the competitive capacity of an industrial company. The results obtained were an increase of more than 700% in the Mean Time Between Failures and a reduction of 40% in the Mean Time Between Repairs (Carvahlo and Sellito, 2015). Likewise, the successful implementation of this tool requires the support and commitment of senior management and a greater sense of responsibility on the part of the workers (Lee, 2015).

B. Systematic Layout Planning

Systematic Layout Planning is based on plant layout optimization and has been studied by numerous international academics to solve industry planning problems. It serves to analyze the logistic relationship between each operation (Liu *et al.*, 2020).

This procedure begins with the collection of input data and activities. Then the relationship between the flow of materials

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and the activities carried out is analyzed using a relational diagram, the floor space is calculated using a plan, and its possible modifications and limitations are analyzed. From this, one or two alternative design proposals will be developed. Finally, the impact it would have on the route is evaluated, and whether it is optimal to change the plant distribution (Suhardini and Septiani *et al.*, 2017). Systematic Layout Planning is a tool that allows for improving the plant design by identifying the problems of the current invention. An investigation carried out in a company showed that the work sequence and the production flow could be reorganized. It results in a reduction of almost 40% of the route and an increase in production (Wiyaratn and Watanapa *et al.*, 2013).

C. Total Productive Maintenance

Total Productive Maintenance explains how through total participation, it is possible to control the entire process, eliminate waste, have improvements of equipment utilization, and obtain the maximum benefits (Zhai and Zhang, 2016). Singh and Khamba *et al.* (2020) referring to this tool highlight the importance of focusing on the six significant losses of this methodology: time, quantity, setup, speed, quality, and performance. To measure its application, Overall Equipment Effectiveness (OEE) is an indicator used to improve machine performance and reduce production costs. This one incorporates metrics about machine conditions into a measurement system. The values of this indicator are derived from the calculation of the level of Availability, process efficiency, and the quality rate of the product (Herry and Fariada *et al.*, 2018).

Total Productive Maintenance can be combined with other tools or media. In a study on the combined use of this tool with the 5S methodology, an Overall Equipment Effectiveness was obtained in each machine greater than 80%, giving one company a competitive advantage over others (Rizkya and Sari *et al.*, 2020).

D. Total Productive Maintenance of Systematic Layout Planning

In research on Systematic Layout Planning, Bagaskara and Gozali *et al.* (2020) mentioned that an improvement in the production line was a better organization of machines and a reduction in transfer times. In study of Chukwutoo and Paschal (2018) on Total Productive Maintenance, the OEE was increased by an average of 5 percentage points. It was shown that the main problem with the machine was its production capacity.

In a combined model of Total Productive Maintenance and Systematic Layout Planning, applied in the textile sector of a Peruvian company, it is indicated that the importance of the application of both tools is that this model not only focuses on the improvement of equipment, it also optimizes the path of the operators during the process. The implementation of the model lasts three months (June, July, and August) and works in 8 phases. The results of the implementation of this model were encouraging since it was obtained that the Overall Equipment Effectiveness increased from 68.21% to 84.38%, and the travel time was reduced from 1832.3 to 1592.45 seconds; that is, a reduction of 13.09% (Quispe and Takahashi *et al.*, 2020).

III. Contribution

A. Model Basis

Lean Manufacturing has many tools that solve problems such as order, cleaning, setup times, downtime, and provisioning. However, if we combined these tools with others, many significant issues could be covered, and new devices could be developed.

After having carried out an exhaustive review of the literature, it was found that, by jointly implementing the Total Productive Maintenance tool and Systematic Layout Planning, it is possible to increase the Productivity of companies and develop a competitive strategy in the sector. In addition, it was found that the company's Productivity was lower than that of the sector and the causes that originated it was analyzed (See Table I).

TABLE I: Comparative Matrix of Causes VS State of Art

Causes / Article	Lack of previous studies and/or use of a tool for plant design	No adequate arrangement of the machines during the production process	A maintenance plan was not developed
Carvahlo, N., Sellito, M.	-	-	TPM
Wiyaratn, W., Watanapa, A., Kajondecha, P.	SLP	-	-
Herry, A., Fariada, F., Lutfia, N.	-	-	TPM
Quispe, H., Takahashi, M., Carvallo, E.	-	SLP	TPM
Proposal	TPM	SLP	TPM

B. Proposed Model

The proposed model (Fig. 1) is based on the combined implementation of the Total Productive Maintenance and Systematic Layout Planning tools. The TPM methodology is used in large companies for the improvement and optimization of their maintenance processes. Originally it contained eight pillars for its implementation. However, since the study will be conducted in SMEs, only the first three will be used as they better fit these companies' current situation and needs. The selected pillars are Focused Improvements, Planned Maintenance, and Autonomous Maintenance.

The model seeks that through the implementation of TPM and SLP, the company's production flow is optimized, and consequently, Productivity is increased.

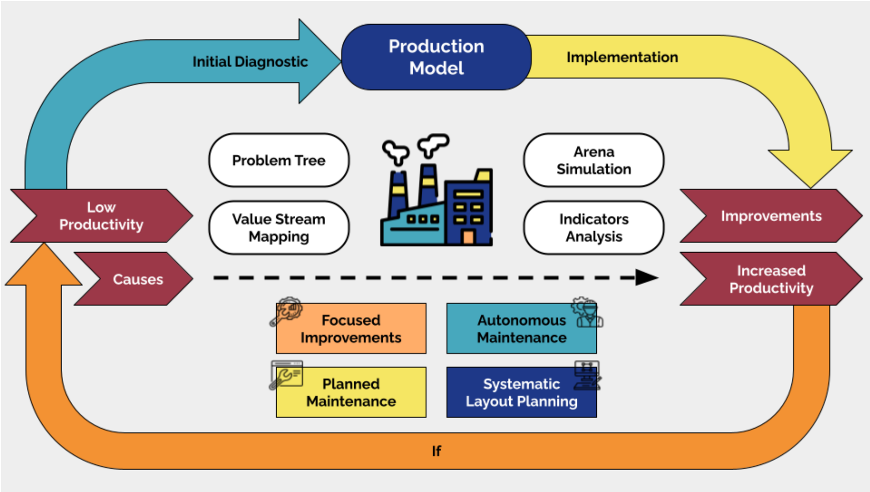

Fig. 1. Proposal model.

C. Model Components

Next, each of the four stages of the proposed model will be explained in more detail:

1) Focused improvements: This stage focuses on detecting root causes of failures in machines and/or production processes to propose a solution that minimizes or eliminates the negative impact these can cause. For this, the Failure Mode and Effect and Causes Analysis (FMECA) methodology will be applied, which allows organizing the faults found, analyzing the effects they can cause, and calculating the criticality of each one. From this, it is proposed what type of maintenance and/or prevention actions should be taken.

2) Planned maintenance: In this stage, a maintenance work plan will be carried out based on the critical points previously found, which details the information and specifications of the machines to be evaluated, as well as the maintenance activities that must be carried out, considering the duration, responsible and requirements of each one. So that machine failures and breakdowns can be prevented or corrected within a short time.

3) Autonomous maintenance: For this third stage, a training plan will be drawn up for machine operators, allowing them to learn more about their preventive maintenance and inspection and cleaning actions that must be carried out periodically. Additionally, routines will be implemented to reinforce this knowledge so that operators can be aware of the actions that must be carried out in their work area.

4) Systematic layout planning: This stage begins with recognizing the flow of materials and the relationship presented by the production activities. Then a relational map is drawn up, from which a new plan design proposal will be presented concerning the original plan. For this, the relationship between the areas of the plant and the effects of the change in the production process must be considered, which will be evaluated from the operator's run distances. Finally, it will be evaluated if it is feasible to redistribute the plant based on the new design.

D. Indicators

In this research, the following indicators are used to evaluate the improvements of a model based on TPM and SLP:

- *Productivity*: Is measured by dividing the company's income by its expenses.

Objective: Increase Productivity by 5%.

$$Productivity = Incomes / Expenses$$

- *Mean Time Between Failures (MTBF)*: It is the time during which a machine does not present failures. It is essential to be precise that about OEE, there are two factors (Performance and Quality) that are good in the company. So, to improve Availability, the indicator MTBF is used.

Objective: Increase the MTBF value of rectifier machines by 40%.

$$MTBF = Number\ of\ operational\ hours\ / \ Number\ of\ failures$$

- *Mean Time to Repair (MTTR)*: It is the average time to repair machinery. For this case is 45 hours.
- *Cycle time:* It is the time that the entire production process lasts.

Objective: Reduce cycle time by 10%.

$$Process\ time = \sum Time\ of\ each\ activity$$

- *Availability:* This is a percentage of operation time out of total time.

Objective: Increase Availability by 3.5%

$$Availability = \frac{MTBF}{MTBF + MTTR}$$

IV. Validation

To validate the improvement of the proposed model, which representation is observed in Fig. 2, the Arena software is used, which allows for obtaining the necessary data for the improvement analysis, such as the number of entities and cycle time. It is important to emphasize that all the results only come from simulation. It was not possible to run a pilot plan due to COVID-19.

A. Initial Diagnosis

Analyzing the company's current situation, it was found that the biggest problem was Productivity. In monetary terms, it is currently 1.43 soles of income for each sol of exit, and the average Productivity of the sector is 1.51. This low Productivity costs the company 8856.24 soles, which represents 5.25% of the company's annual costs. The leading causes that explain this low Productivity are Incorrect plant layout, sudden stoppages of the production line, and the lack of preventive Maintenance. The following are the results of applying the proposed model in conjunction with analyzing the indicators.

B. Validation Design and Comparison with the Initial Diagnosis

For the validation of this proposed model, the test in Arena was carried out for 12 months, from November 2021 to November 2022, on the Maintenance of ceramic manufacturing molds. These changes or improvements applied to the improved model have no differences in the structure of the process. It remains the same as the current model. The changes are in the processes in which there is the transfer of materials. It is optimized through Systematic Layout Planning, which evaluates distances to reduce travel times.

The other changes occur in machine stops, which are in charge of Total Productive Maintenance. It could be evaluated in more detail using a pilot test; however, due to the pandemic, this could not possible. So, the changes are based on one of the pillar papers of this article, in which they reduced repair times by 98.55% and increased the Mean Time Between Failures of the machines by 60%.

The current indicators of the company versus those expected are detailed in Table II.

TABLE II: TABLE OF INDICATORS

Indicator	Actual situation	To be
Cycle Time	198.55 hours	178 hours
Number of processed molds	46	50
MTBF	300	405
Productivity	1.43	1.50

C. Improvement-Proposal Simulation

On the other hand, to carry out an exhaustive analysis of the effects of applying these tools, a simulation model was created in Arena, which was used to demonstrate the displacement times of raw material and repair times, as well as increased times between machine failures. The process was represented from the arrival of the molds, the disassembly, the maintenance process, assembly, and the order packaging.

It was determined that the optimal number of replications for the current model is 500, with an error of 0.6%, and for the improved model, 500, with an error of 0.9%. After these calculations, the model was run, which yielded the following detailed results in Table III, which shows the reduction of the times between outputs of the assembled molds and a more significant number of entities in the process output.

TABLE III: ACTUAL SIMULATION VS IMPROVED SIMULATION

	Cycle Time (hours)	Time Between Departures (hours)	Number of molds coming out of the system	Mean Time Between Failures (hours)
Actual model	198.55	67.17	46	300
Improved model	169.69	59.37	51	448

The results of the implementation and simulation of this case study are as follows:

- Mean Time Between Departures was reduced from 67.17 to 59.37 hours, making the process more efficient. It has decreased by 11.61%.
- The decrease in the cycle time is 14.54%.
- The number of molds with Maintenance completed has increased by 9.80%.

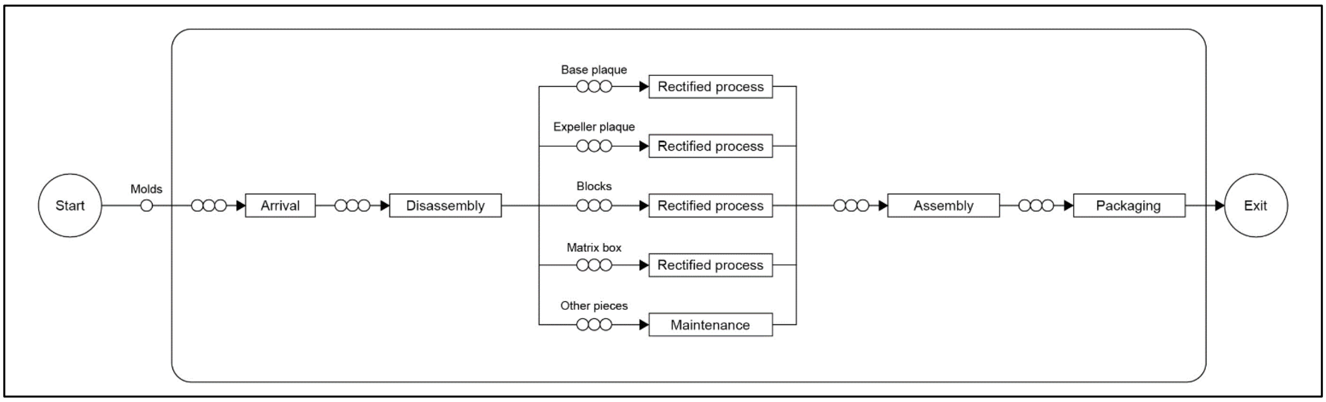

Fig. 2. Representation.

Regarding the Availability of machines, the company takes approximately 45 hours to repair the machinery. It is known as Mean Time to Repair or MTTR. Considering the availability formula in the actual model, this indicator is 86.96%, and in the improved model is 90.87%. There is an increase of 4.50%, so this indicator is now within international standards.

On the other hand, the reduction in time between exits impacted the number of entities that exited the system seeing this way increase from 46 to 51 molds with finished Maintenance when running the model in such a way that the number of outgoing entities is 46. In the current model, a total of 3044.42 hours elapsed, and in the improved model, a total of 2764.60 hours. Here a difference of 279.82 hours is observed, considering that they work 8.5 hours daily. The number of workdays that were reduced to perform Maintenance on 46 molds is 32.92 days.

The application of these tools significantly impacts the maintenance times of a mold, thus having more molds that can be served per year.

As mentioned above, the company's Productivity is 1.43, of which 50% is explained by machinery, 20% by raw material, and 30% by labor.

For the 46 molds, the amount of labor is considered constant; however, the materials are increased since 51 molds are made in the improved model. Consequently, it would have a value of 0.317 soles of income per soles of exit. Machinery represents 50%. Therefore, its new value will be 0.793. The Productivity of 1.54 soles of income per soles of exit is obtained.

V. Conclusion

It was possible to demonstrate that implementing Lean tools is feasible since Productivity grew by 7.69%, surpassing the initial objective.

It could be shown that by reducing the process path by 75.64 meters, the cycle time was reduced by 27.83 minutes. In the simulation, this results in a reduction of up to 32.92 days per year.

In the future, emphasis should be placed on the tail of the rectification processes of the latrines as well as the traps in which there was an excessive waiting time within the simulation (12 molds to be processed). It can be solved if the company invests in another 1M grinding machine or looks for some way to alternate the machines to reduce the molds to be processed.

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Carlos Seminario-Mestanza developed the models and analyzed the data. Andrea Soto-Araujo conducted the research and wrote the manuscript. Martín Collao-Diaz, Juan Carlos Quiroz-Flores and Alberto Flores-Perez, with their extensive knowledge and professional career, served as a guide for the course of the investigation. All the authors had approved the final version.

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