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Application of Lean Manufacturing Principles to Increase Machine Availability in Peruvian SMEs in the Textile Sector

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Abstract. Based on figures in the textile industry over the past years, it can be assumed currently that this industry is one of the most important markets in different countries because of high consumption. Due to economic value and the increasing work activities in the textile sector is related to the last trends in fashion. However, there are still challenges to overcome for instance: low availability of machines or poor human resources management generate economic and productive impacts. Within this context, it arises the need to propose an integrated model combining Total Productive Maintenance (TPM) and Lean Leadership which supports and creates a synergy between maintenance management and human resources; by using tools such as the orders and maintenance plan, system simulation in two comparative scenarios, a continuous system assessment combined with 5S methodology, and providing education and training in good practices in lean Leadership. Thereafter, the model was implemented, the availability indicator was calculated to attack the main problem and as result, it had an increase of 10.56%, this increase supports optimally and validates the proposal of the present study.

Keywords: total productive maintenance, lean leadership, 5s, textile industry, availability, SMEs

1. Introduction

The textile industry is one of the most important markets around the world due to high fashion consumption in developed countries. [1] The present paper defines the integration of engineering tools to improve machine availability in the production area of a small and medium-sized textile enterprise. Likewise, it is observed the improvement of the process and also an increase in profitability since the textile industry has a higher impact on Peru's economic growth. [2] The textile industry sales from January to June 2019 period were 17 203 in thousand units and sales for the year 2020 during the same period were 3 659 in thousand units, it is observed a decrease of 78.7%. [3] This reduction indicates that the micro, small and medium-sized enterprises of the textile industry have some problems in their process which prevent from increasing their sales.

The problem that faces the textile industry, regarding with the literature, is associated with different causes that are common when good practices are not carried out such as maintenance management, human capital management, process optimization, or simply these practices are not considered. Some of the major causes found to lead to create difficulties, for instance: increase in downtime for repair, sudden equipment failures, operator's absence, etc. In one case study, it was detected four main causes of the defect in machine operability: human neglect, lower quality raw materials, low performance in machines, and work procedures [4]. In another case study, it was detected a significant loss in a spinning machine for clothing production and the causes for breakdown stoppage were mainly due to energy failure, breakage in draft change pinions (DCP), gear torsion change pinion (TCP) [5]. Difficulties described previously indicate a chief obstacle due to poor performance in the maintenance field so that they reflect on a higher number of textile departments do not have optimal management of their resources due to a lack of maintenance plan and reduce the productivity. A maintenance plan implementation not only helps to reduce the cost of machine failures but the quantity in fabric losses and thus increase the production performance [6].

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As the evidence above, it is important to implement appropriate techniques to help in the improvement of material and human resources. As observed previously, it is important to implement to this manufacture appropriate techniques to improve its resources, material, and human resources as well. This requires a case study that describes the problem in the textile sector. The finding of the waste namely higher downtime, increase in maintenance expenses, and an important number of emergency repairs. According to the difficulties encountered previously it was developed a sequential work scheme based on TPM was to reduce or eliminate problems [7]. The present study provides a combined new model that is applied for improvement and increase machine availability. Thus, in this way, achieve the goals and maintain a growth tendency.

It should be emphasized that there are few studies on small and medium-sized enterprises in the textile sector regarding an integrated implementation of engineering techniques in one single case study with the search to improve the availability of machines. That is why the need for the present investigation arises. This scientific article is divided into seven parts: Introduction, includes successful cases and is explained in detail techniques and tools; the analysis of the problem, the indicator points out the main problem and the economic impact; the state of the art contains the typologies of the present study; the contribution describes in the comparative matrix, deployment of each tool; results and validation by using the Arena Software in the simulation of the proposed model; the discussion, how is analyzed scenarios and at the end acknowledgments and references.

2. State of the Art

Articles selected from the state of the art were assessed by different authors regarding identified failures in search of improvements through maintenance management and human capital. The case studies are presented as follow:

2.1. Total Productive Maintenance (TPM)

The TPM Tool implements the improvement that is designed to optimize the availability of the machines through empowerment and involvement of all manufacturing workers and maintenance duties. It can be understood with the case studies the importance of maintaining good practices and the benefits of planning from inception besides avoiding negative effects like not performing reactive maintenance or being out of time during working hours. Likewise, the findings in studies have developed the improvement in Overall Equipment Effectiveness (OEE). Besides, it is necessary to eliminate six failures in main equipment as equipment failure, set up and adjustments, process defect, reduced speed, and minor stops. [8-9]

Additionally, some further research finds that autonomous maintenance is a TPM good tool because the operator carries out maintenance tasks and reduces its cost. [10]

2.2. Lean Leadership

Lean Leadership philosophy has as the main objective that all the employees must be a model to follow by themselves, in other words, mutual admiration. Besides, it motivates the executives to be in the organization observing the process and correcting the errors by themselves. [11] Literature shows that leadership is a methodic system for sustainable implementation and continuous improvement in production and it describes how executives and leaders cooperate in a mutual effort for perfection [12]. Research shows that leadership has been identified as a critical factor of success in Lean implementation. In another case, if it is decided to implement Lean Manufacturing it is necessary to include Lean Leadership as well. Furthermore, investigations reveal that any type of leadership works and if it is correlated it is much better. [13-14]

This research will be used to develop a theoretical framework based on the dynamic of the systems to shape the worker's performance and evaluate different scenarios for improvement [15]. The objective of the research study was to analyze how was the worker's behaviour style in communicating and spreading the information on the importance of leadership in a small and medium-sized enterprise. As result, the workers ignore the open communication at the beginning but when the communication was implemented without being informed previously, operators react positively and choose best practices and a good work atmosphere.

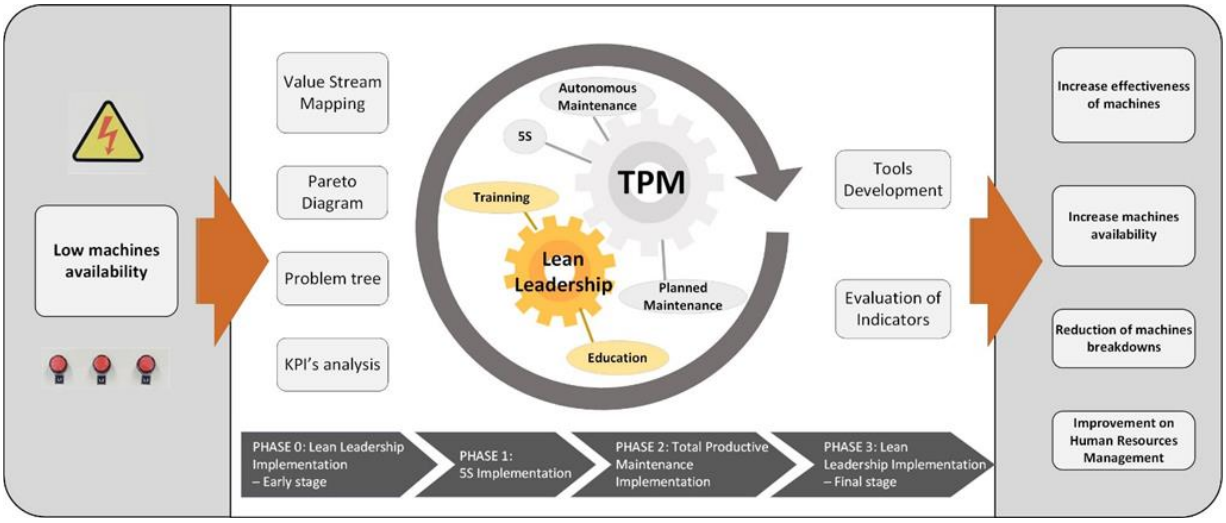

Fig. 1: Main figure of the proposed research model.

3. Contribution

3.1. Model Basis

The value proposal of the study will be presented through assessment tools in the state of art to accomplish the integrated model. It was formulated to solve the main problem of this research which recommends increasing the availability of productive machines of textile manufacture. For this reason, according to the context mentioned, it will search and implement different tools, models, and methodologies for eliminating or diminishing the causes which are the root of the problem. In this context, according to the literature, the current case study will be used Total Productive Maintenance, the most required set of tools to solve the main problem, and also human resources management with Lean Leadership.

The figure of double-entry identifies different sets of tools used in the state of art.

Table 1: Comparative Matrix of Proposed Components vs State of Art

Components	Maintenance management	Human capital management
Xiang, Z. T., & Feng, C. J. [16]	TPM & Lean Planning	
Rodrigues, J., de Sá, J. C. V., Ferreira, L. P., Silva, F. J. G., & Santos, G. [17]		Lean Leadership, Yokoten
Quispe-roncal, H., Takahashi-Gutierrez, M., Carvallo-Munar, E., Macassi-Jauregui, I., Cardenas-Rengifo, L., [18]	TPM	
Ahmad, N., Hossen, J., & Ali, S. M. [19]	TPM	
Bataineh, O., Al-Hawari, T., Alshraideh, H., & Dalalah, D. [20]	TPM & 5S	
Proposed Techniques	**TPM & 5S**	**Lean Leadership**

3.2. Proposed Model

The proposed model is the integration of Total Productive Maintenance and Lean Leadership by increasing the machines availability in the manufacture of the textile sector. It will be implemented in different phases and this research will require the following inputs: operating time, available time, reactive and preventive maintenance time, the quantity of incoming and outgoing garments in the process, frequency of absenteeism of operators, and the number of operators in the working area. With all the information it will examine the current situation of the case study, then analyze the problems, identify the causes and root of the problem.

3.3. Model Components

The model has many phases in TPM and Lean Leadership described step by step as follows

A. Phase 0: Lean Leadership Implementation – Early stage

Phase 0 or starting phase includes all preliminary activities and shows every technique. The first step gathers all the workers of the case study and informs them about the current situation of the company and lets them know about diagnosis and problems.

The second step, initiated by sending the communication to the workers about the concepts in general and the set of tools to use. Then it begins the implementation of an integrated model using the initial phase of Lean Leadership which helps in analyzing the level of good practices of Lean Leadership applied before the technic intervention. At the same time, the workers must be trained and educated about the principles of the techniques.

B. Phase 1: 5S Implementation

Phase 1 is the previous stage before using the selected pillars of TPM. At this stage, it will be developed 5 sets of tools of the technique: (Seiri) Sort, (Seiton) Set in order, (Seiso) Cleanliness, (Seiketsu) Standardize, and (Shitsuke) Discipline. Every "S" defined a different concept which adds value to the final objective of the methodology that results in a clean workplace, well organized in good conditions, in order, cleanliness and discipline.

In the beginning, it involves a visual mapping (Gemba Walk) to implement the abovementioned methodology in the workplace and analyze and evaluate the actual situation. In the present study, the focus is on clothing area. In that way, a checklist will be used as a toolbox for evaluation if it is applying each one of 5 "S". Meanwhile, the actual workplace regarding 5S good practices will analyze afterward, it will implement the improvements by organizing the workplace, eliminating existing waste, and reducing time used for each activity.

C. Phase 2: Total Productive Maintenance Implementation

In development Total Productive Maintenance is necessary to know and evaluate data about different machines, namely: operating time, available time, preventive and corrective maintenance time, information gathered while the intervention lasted, it means the period for evaluation.

The pillars of TPM used for this research are autonomous maintenance and preventative maintenance and choosing the tools like maintenance order and maintenance plan which will help in organized planning within maintenance management.

D. Phase 3: Lean Leadership Implementation – Final stage

At the end of the whole implementation, a final self-evaluation will be carried out to all the workers that participated in the initial self-evaluation by considering their point of view and evaluating the impact of Lean Leadership in the organization. The questionnaire and questions are the same as the initial self-evaluation and the difference between both is that the final self-evaluation contains all the incidents during the implementation period of the integrated model. While comparing previous and post-self-evaluations there is a gap to evaluate

3.4. Indicators

Indicators are essential to measure and understand the results obtained by using the proposed model as follows:

- Machine Availability Rate: This indicator seeks to measure the percentage of time during which the machine is ready to operate without any external malfunction.

$$\text{Availability} = \frac{\text{Operating Time}}{\text{Available Time} - \text{Planned Maintenance Time}} \text{ x } 100\ \%$$

According to Nakajima's theory, the ideal level of this indicator is 90%, which means machines operate in an acceptable condition.

- Mean Time Between Failures (MTBF): Measure the average time of a machine that can operate without failures. To calculate this indicator, it will be used the following formula:

$$\text{MTBF} = \frac{\text{Total Operational Hours}}{\text{Number of Failures}}$$

The objective of meantime between failures is to maximize the value so that this is the greatest possible so that the machines maintain their operation for a longer time.

- Mean Time to Repair (MTTR): It is the average time a machine takes to be repaired. This indicator is measured as follows:

$$MTTR = \frac{\text{Total Maintenance Time}}{\text{Number of Repairs}}$$

The objective for average time to repair is minimizing the value because the time to restore will be the quickest.

- 5S Index Assessment: This indicator calculates from 1 to 10 scale the average rate for a performance about good practices in 5S methodology.

$$\text{5S Assesment Rate} = \frac{\sum(\text{Sort} + \text{Set in order} + \text{Clean} + \text{Standardize} + \text{Discipline})}{5}$$

This indicator is the total addition obtained of each "S" in the score of the methodology divided into 5 to obtain the average score of the assessment. This is the measurement of commitment of good practices of the 5S methodology.

- Absenteeism Rate: This indicator calculates the percentage of absences of the operators during a period namely, milestones, days, months, etc. The calculation obtained must be sum the number of absences and divided by the number of working days in a period.

$$\text{Absenteeism Rate (\%)} = \frac{\text{Number of Missed Workdays}}{\text{Number of Workdays}}$$

With this indicator is expected that absences will be as lower as possible, maximizing the operating time of operators.

Table 2: Actual Indicators vs Expectations

Indicator	As Is	To Be
Machine Availability Rate (%)	82.54%	90.00%
Mean Time between Failure (hours/failure)	52.49	60.37
Mean Time to Repair (hours/failure)	12.13	4.85
5S Assesment Rate	4.4	10
Absenteeism Rate	19.33%	17.79%

4. Validation

This paper will use techniques in the Lean Leadership – TPM model applied in the Clothing Sector of a small and medium-sized enterprise. The resources of information to evaluate come from that sector. Previously, it has made a diagnosis and found causes from the main problem, next it defined the techniques to apply and then it proposed an integrated model so that it can fill the gap in knowledge and implement an improvement to the case study.

4.1. Initial Diagnostic

Observing the initial diagnostic, it is noted that the actual situation of availability of machines is 80.59% which generates the need for improvement for the case study because the ideal level for the research is 90%. In the same way, the technical gap is relevant because it leads to economic losses of S/. 6 127.44, 3.19% of the total cost. In the same way, the main causes for low availability of machines are low speed and noisy, which is not common in machines, wear internal components, messy and non-clean workspace, no usage of machine manuals, operator´s absenteeism in working days and assign secondary tasks to operators by relegating from their essential work formation.

4.2. Validation Design and Initial Diagnostic Comparison

To apply the proposed model and its validation, it has gathered the necessary data in three months from June 15th to September 15th, 2021. Jogger pants were the garments chosen for this research. The initial component applied to Lean Leadership technique and did self-evaluations to know the actual situation of the case study also training the operators on Lean Leadership techniques as a part of their education. Using all the components of the model at the end of the research, a post-self-evaluation has been done to obtain a comparison between previous and post-evaluation of the situation.

Completed the initial component, the 5S methodology has been applied for organizing the workplace and cleanliness. Afterward, it has applied a graded evaluation as a tool to know the initial situation and improve it. Additionally, the research study has validated on TPM pillars, by using the Arena Software 16.10 to simulate and compare the actual and improved situation, thus it proposed another system.

4.3. Simulation of Improvement Proposal

To confirm the effectiveness of the proposed model, a simulation was carried out to determine the increase in operating machine availability of clothing area. This can be presented graphically in the initial situation representation in figure 2.

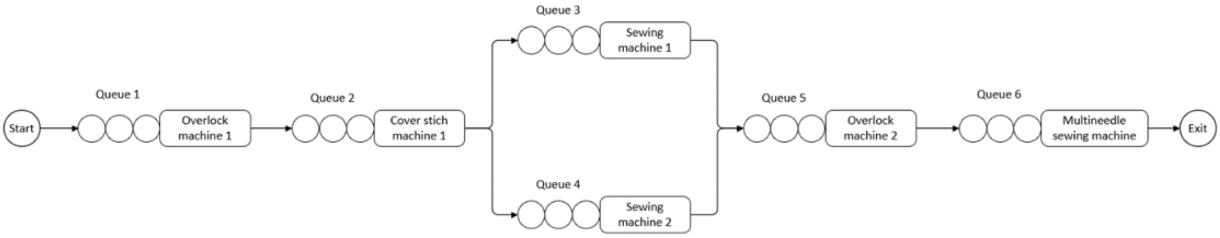

Fig. 2: Graphical representation of the current system

The actual situation in the graphic is presented with the help of the simulator Arena Software, a new model built for the actual scenario, and another improvement for the clothing area, which can be seen in figure 3.

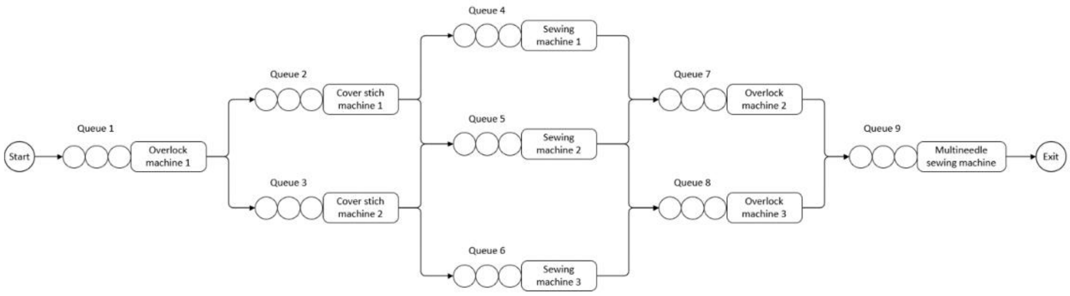

Fig. 3: Improved system graphical representation

For the optimum scenario, it was implemented the effect of the 5S methodology by reducing operating time, considering that the activities of the area are efficient due to cleanliness and setting in order in conjunction with the pillars of Total Productive Maintenance and Lean Leadership. All this lets the simulation validate the improvement implemented in the clothing area since the optimal scenario it is proposed according to an increase in parallel machines because of their major availability.

Table 3: Actual Situation Indicators vs Improved Situation

Indicator	Actual	Improved	Variation
Machine Availability Rate (%)	82.54%	91.25%	(+) 10.56%
Mean Time between Failure (hours/failure)	52.49	56.71	(+) 8.04%
Mean Time to Repair (hours/failure)	12.13	5.72	(-) 52.88%
5S Assesment Rate	4.4	7.6	(+) 72.73%
Absenteeism Rate	19.33%	11.84%	(-) 38.75%

Finally, to calculate indicators as a result of the implementation and the simulation it observed an optimization of the research study indicators. Table III illustrates results obtained in comparison with the initial results situation which originate a variation between the two situations and proved that the proposed model increases in machines availability.

5. Conclusions

It is observed that the development of the TPM- Lean Leadership integrated model can reach 10.56% of machine availability for small and medium-size textile enterprises. Therefore, it increased the mean time between failures to 8.04%, and the meantime to repair machines decreased in 52.88%. Furthermore, the achievement of the 5S methodology in production area reflected an increase of 72.73% since the 5S evaluation. The absenteeism rate was reduced in 38.75%. With all of this mentioned it showed the effectiveness of the engineering techniques applied to the case study.

For future research, it is recommended to focus on other areas of manufacturing process such as measurement of productivity or supply chain management analysis since part of the continuous improvement is looking for improvement opportunities and achieving better benefits.

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