Maintenance Plan Based on TPM for Turbine Recovery Machinery

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Abstract. The maintenance and repair of the components of hydroelectric turbines require the use of specialized equipment. To keep these teams operational, it is proposed to design a master plan in order to develop a TPM philosophy for a vertical turning lathe. This project develops five of the twelve steps established by JIPM for the TPM implementation. This paper also provides the necessary documentation for 5S and autonomous maintenance applications. Also, some safety, health and environmental suggestions are provided. PM activities are chosen based on RCM techniques like CA and FMEA. And predictive maintenance activities are established following ISO 3655, 2006. All these activities including automotive maintenance ones are organized and scheduled. Finally, OEE rate is applied to the lathe to identify the principal losses on the machine. After applying this proposal there is an increase of 27.84% and 39.71% in availability and performance respectively. The OEE calculation has increased by 29.97%, thereby motivating readers to implement this methodology in other industries.

1. Introduction

Industrial maintenance is key for any company. Its main purpose is to extend the useful life of machines and guarantee availability and reliability [1,2]. Even maintenance is considered as a non-productive activity because it does not generate money directly, it is key for manufacturing products with good quality and the efficiency of production systems [3–5]. In 1930, Henry Ford incorporated a maintenance director into his chain production model, starting the concept of maintenance and establishing a team of workers for analyzing and proposing the times in which repair jobs should be carried out [6]. Later, with the canon of reliability, the experts in charge of maintenance seek not only to correct equipment failures but to prevent them so that they do not originate [7]. In this way, several maintenance methods emerged to cover needs in industrial processes: preventive maintenance (periodic review and cleaning systems), predictive maintenance (analysis of equipment using physical variables) and corrective maintenance [8]. Also, there is proactive maintenance (performance of workers in maintenance work), a Computerized Maintenance Management System (CMMS) and reliability-based maintenance (RCM) [9]. At the same time, starting in the 80s, TPM (Total Productive Maintenance) was proposed, where production operators were part of the maintenance of the equipment by being assigned lubrication tasks, adjustments, minor repairs and cleaning [10,11]. It is intended that the production operator is part of the
care of the machines, with the objective of "zero breakdowns". TPM is established with the training, motivation and involvement of the human team with or without the contribution of technology [12]. Over time, Latin America has understood the importance of the proper functioning of equipment and its relationship with the economy [13]. Many public and private companies in the textile, automotive, metalworking, production and manufacturing areas invest part of their resources in improving their maintenance area. In [14] the implementation of TQM and TPM in Indian manufacturing is described. As a result, applying these methodologies for a reasonable time improves the performance of the system. In the work of [15] it is proposed to improve productivity in a tractor manufacturing industry through Total Productive Maintenance (TPM) initiatives. Changes made, cost reduction, and increased OEE doubled sales revenue and tripled profit over a three years. For its part, [16] uses TPM practices to reduce energy consumption in the hotel sector. In this way, the versatility of the use of these tools and the increase in benefits for these companies is demonstrated. In this context, a maintenance center and research laboratory have been created in Ecuador. This center aims to meet the demand for the maintenance, recovery and construction of turbine parts of the country. This proposal describes the development of a master plan of maintenance to incorporate the TPM philosophy in a huge CNC vertical lathe, as the main equipment of this center. Techniques and philosophies such as 5S, autonomous maintenance, CA (criticality analysis) and FMEA (Failure Mode and Effect Analysis) are developed for this purpose.

This article is organized as follows: the introduction in section 1, in section 2 the case study is shown. Section 3 presents the methodology. Experimental results and the conclusions and future work are described in sections 4 and 5 respectively.

2. Case study

Construction, maintenance and recovery of hydroelectric turbine parts are processes that South American industries cannot carry out due to the lack of equipment and specialized workers. This is why the Ecuadorian industry has made a big investment with the acquisition of the necessary equipment for the implementation of a laboratory that allows the production of these turbines. This center has an operational capacity to repair runners of up to 30 tons and 4 meters in diameter through polishing processes, manual and robotic welding, machining, heat treatments and quality control tests required for the recovery of the hydraulic turbine parts. The most important equipment of this center is a 3-axis CNC vertical lathe designed to machine large runners with a diameter of 4 meters and a turning height of 2.5 meters with a precision of 0.001 mm. This laboratory needs to develop world-class maintenance practices which are why TPM philosophy (Total Productive Maintenance) has been chosen for this purpose [15]. As a pilot plan, most of the pillars of TPM will be implemented on the whole center, but the maintenance plan will only be carried out in the vertical lathe [17]. This is the first test phase before the subsequent implementation of this type of maintenance in all equipment of the laboratory. The CAD design of the 3-axis CNC vertical lathe is presented in Fig. 1.

![BOST CNC SMART 50CH-4000 vertical lathe.](image)
The main purpose of TPM is reducing failures, downtimes and increasing OEE (Overall Equipment Effectiveness). This is made based on autonomous and scheduled maintenance activities. Another advantage of TPM is that reliability is ensured and the useful life of the equipment is extended. The base of TPM is 5S and there are 8 pillars which are shown in Fig. 2.

3. Methodology

3.1. 5S implementation

The 5S system operates based on 5 Japanese principles that allow managing the application of activities of order, cleaning and detection of anomalies in a workplace. To implement 5S in this center it has started a campaign to use red cards to identify unnecessary elements in the whole center. After that these items were removed in correspondence to the first pillar “Sieri” or Sort (classify, select and organize). In Fig. 3 the removal of unnecessary elements in the area around the vertical lathe is shown.

After that, the second pillar of 5S was implemented - “Seiton” (Set in order) where the needed items for daily operations were set in the strategic and specific places to allow for easy and immediate retrieval. Also, signage of the holders was established to make it easier to find the right place for the tools. This is shown in Figure 4.
Third, the fourth and fifth pillar of 5S (Shine, Standardize and Sustain respectively). For these pillars, it was taken a whole day to clean the entire establishment with the help of all the company workers. The standardization of cleaning activities was established in the maintenance plan with a monthly frequency. These activities will be developed by operators of the machines and evaluated by the area managers.

3.2. Autonomous maintenance implementation

The purpose of autonomous maintenance is that the operators do some equipment care independently of the maintenance staff. After the standard conditions have been established with the 5S. The operators of the CNC lathe must make daily inspections to keep these conditions. Several standards were established for the lathe, especially for lubrication and cleaning activities. Before the use of the machine, the operator must check the level of the lubricants in the different checkpoints of the lathe. If the operator finds any abnormality in his daily inspection he must report this one with the help of yellow cards that were also established for this purpose. Table 1 describes the standards of the main lubricants used.

Table 1. Lubrication standards.

| Reservoir | Diagram | Oil type | V(l) | Frequency of change |
|-----------|---------|----------|------|---------------------|
| A         | Hydraulic group 10030-13-001 | ISO VG 32 | 250  | Once a year         |
| B         | Unimec lubrication 10030-13-003 | ISO VG 1000 | 5    | Check level         |
| C         | Skid nuts and guides lubrication | ISO VG 68 Guides 3 | Check level |
| D         | Hydrostatic lubrication and greasing 10030-13-005 | ISO VG 32 Mix | 750  | Once a year         |
| E         | Fluid Cutting Scheme 10030-13-006 | Coolant | 1000 | Once a year         |
| F         | Hydrostatic X/Z 10030-13-007 | ISO VG 68 | 150  | Once a year         |
| G         | Transfer fluid cut | Coolant |
| H         | Hydrostatic refrigerator and greasing10030-13-005 | |
| I         | X / Z hydrostatic refrigerator 10030 | |

3.3. Planned maintenance

To develop planned maintenance it is crucial to develop three steps: a failure mode and effects analysis of all the components, criticality analysis and propose and schedule maintenance activities.

3.3.1. Failure mode and effects analysis. A list of all the components of the machine in a hierarchical structure was established to develop a failure modes and effects analysis (FMEA) [18]. Where the failure
modes are analyzed based on weighted criteria as suggested in the NTP 679 regulation. These criteria are operated to calculate the Risk Priority Number (RPN), which is shown in (1).

\[
RPN = D \times G \times F
\]  

(1)

Where:

D = Failure detectability
G = Severity of its occurrence
F = Frequency of occurrence

FMEA allows the analysis of each component and parts function of the equipment and its failure mode. Also, it helps to determine corrective actions to be taken to prevent the failure based on the analysis of its causes and taking care of its effects. Once the RPN value of each component is obtained, the average is determined. The components that have a RPN higher than the average will be identified as requiring a greater emphasis on maintenance. In total, 192 components were evaluated and an average NPR equal to 52. 77 components got an equal or higher value of the average. This means that 40.10% (77/192) of the components are prone to failure during their operation and must be considered in the maintenance plan. This information is presented in a summarized form in Table 2.

Table 2. Summary of failure mode and effects analysis

| Component            | Failure mode                  | Qty | Failure Effect | F Failure cause | G | D | RPN   | Corrective actions                      |
|----------------------|-------------------------------|-----|----------------|----------------|---|---|-------|-----------------------------------------|
| Transformer          | High output                   | 7   | Short circuit  | 3 High energy  | 8 | 4 | 96    | Cleaning and checking                   |
| Filter (oil and grease) | Plugged                      | 8   | Contaminates   | 6 Contaminates 6 | 5 | 180 |       | Cleaning and parts adjustment           |
| Compressor           | Noise and vibration           | 8   | Doesn’t transport fluid |        | 7 | 3 | 84    | Eliminate noise and vibration           |
| Hydraulic solenoid valve | Leakage does not regulate    | 8   | Doesn’t regulate fluid flow | 5 Fracture | 7 | 3 | 105   | Check                                   |
| Profibus module      | Low signal output             | 2   | Failed to transmit information | 3 Overheat | 7 | 3 | 63    | Visual inspection                       |
| Serial module        | Overheat                      | 1   | Communication problems | Overheat | 7 | 3 | 63    | Visual inspection                       |
| Electric motors      | Vibration and noise           | 7   | Doesn’t generate movement | 4 Misaligned | 8 | 3 | 96    | Cleaning and checking                   |
| Plate                | Parameter deviation           | 6   | Machining imprecision | 4 Misfit and fracture | 9 | 2 | 72    | Part readjustment                      |
| Barron               | Vibration                     | 3   | Doesn’t turn    | 3 Misaligned   | 8 | 3 | 72    | Readjustment                           |
| Tool holder          | Minor problems                | 2   | Tool holder     | 3 Contaminates 7 | 3 | 3 | 63    | Cleaning and inspection                |
| Hydraulic reservoir  | Minor problems                | 3   | Fluid leak      | 3 Contaminates 9 | 3 | 3 | 81    | Tank cleaning                          |
| Cooling pumps        | Internal leakage and noise    | 14  | Systems don’t cool | 4 Maladjustment and erosion | 10 | 3 | 120   | Measure vibration and align motor shaft |
| Hydraulic fluid      | Minor problems                | 4   | Doesn’t carry power to the circuit | 4 Common fault | 8 | 3 | 96    | Change oil and check                   |
| Grease tank          | Minor problems                | 4   | Fluid leak      | 3 Contaminates 8 | 3 | 72 |       | Cleaning and filling                   |
| **Total**            |                               | 77  |                |                |   |   | **Average** | **102** |
3.3.2. Criticality analysis. The criticality analysis is a process by which assets are assigned a criticality rating based on their potential risk-taking care of its frequency and its severity. In equation (2) you can see the criticality calculation and in equation (3) the consequence of the failure. The criteria that have been established to determine criticality are presented in Table 2 and the criticality calculations are shown in summary in Table 3 and Table 4.

\[
\text{Criticality} = FFF \times C \\
C = (IP \times OF) + CM + SHA
\]

Where:
C = Consequence or severity of the failure.

Table 3. Criteria for calculating criticality.

| Element                          | Criterion                              | Value |
|----------------------------------|----------------------------------------|-------|
| Frequency of failure (FFF)       | More than 4 fails per semester         | 4     |
|                                  | 2-4 fails per semester                 | 3     |
|                                  | 1-2 fails per semester                 | 2     |
|                                  | At least 1 fail per semester           | 1     |
|                                  | Total stand-by of the machine          | 10    |
|                                  | Partial stand-by of the equipment      | 8     |
|                                  | Impacts at operational levels (unavailability) | 5   |
|                                  | It does not generate any significant effect on the other activities | 1 |
| Operational impact (IP)         | There is no other machine or equipment to replace it | 4   |
|                                  | There is a shared spare option         | 2     |
|                                  | Spare function available               | 1     |
|                                  | More than $801.00                      | 10    |
| Maintenance cost (CM)           | Between $201.00 a $800.00              | 7     |
|                                  | Between $51.00 a $200.00               | 4     |
|                                  | Less than $50.00                      | 1     |
|                                  | Effects on human safety                | 10    |
| Personal safety and environmental impact (SHA) | Effects the environment producing irreversible damage | 7   |
|                                  | Effects the facilities causing severe damage | 5   |
|                                  | Causes minor damage (accidents or incidents) | 2   |
|                                  | Causes an environmental impact whose effect does not significantly affect | 1   |
|                                  | It does not cause any type of damage to people, facilities or the environment. | 0   |
### Table 4. Summary of the calculation and status of criticality.

| Component          | Object                  | IP | FO | CM | SAH | FFF | C | Criticality state |
|--------------------|-------------------------|----|----|----|-----|-----|---|------------------|
| Main panel         |                         |    |    |    |     |     |   |                  |
|                    | Fuse                    | 1  | 1  | 1  | 1   | 3   | 3 | NC               |
|                    | Power supply            | 10 | 2  | 4  | 1   | 1   | 25 | NC               |
|                    | Transformer 480V        | 10 | 2  | 7  | 5   | 1   | 32 | NC               |
|                    | Switch                  | 5  | 1  | 1  | 2   | 1   | 8  | NC               |
|                    | Power supply SINAMIK    | 10 | 1  | 7  | 2   | 1   | 19 | NC               |
|                    | Auxiliary relays        | 1  | 1  | 1  | 1   | 1   | 3  | NC               |
|                    | Protection relay        | 1  | 1  | 1  | 1   | 1   | 3  | NC               |
|                    | Serial communication module | 8 | 2  | 4  | 1   | 1   | 21 | NC               |
|                    | Profibus communication module | 8 | 2  | 4  | 1   | 1   | 21 | NC               |
|                    | Ethernet port           | 8  | 2  | 4  | 1   | 1   | 21 | NC               |
| Cooling panel      | Filter                  | 8  | 1  | 4  | 1   | 1   | 13 | SC               |
|                    | Fan                     | 5  | 2  | 4  | 1   | 1   | 15 | NC               |
|                    | Display                 | 10 | 2  | 7  | 1   | 1   | 28 | NC               |
|                    | Compressor              | 10 | 4  | 7  | 2   | 1   | 49 | NC               |
| Tooling            | Flow switches           | 5  | 2  | 7  | 1   | 1   | 18 | NC               |
|                    | Pressure switch         | 5  | 2  | 7  | 1   | 1   | 18 | NC               |
|                    | Flowmeter               | 5  | 2  | 7  | 1   | 1   | 18 | NC               |
|                    | Level sensor            | 5  | 2  | 7  | 1   | 1   | 18 | NC               |
|                    | Hydraulic electro valve | 5  | 2  | 4  | 1   | 1   | 15 | NC               |
|                    | Presence sensor         | 8  | 2  | 4  | 1   | 1   | 21 | NC               |
|                    | Position sensors        | 8  | 2  | 4  | 1   | 1   | 21 | NC               |
|                    | Renishaw tools          | 10 | 4  | 10 | 1   | 1   | 51 | C                |
| Local panel        |                         |    |    |    |     |     |   |                  |
|                    | Profibus communication module | 8 | 2  | 7  | 1   | 1   | 24 | NC               |
|                    | Serial communication module | 8 | 2  | 7  | 1   | 1   | 24 | NC               |
|                    | Relays                  | 1  | 1  | 7  | 1   | 1   | 9  | NC               |
|                    | Transformer             | 10 | 2  | 10 | 5   | 1   | 35 | NC               |
|                    | Terminal blocks         | 1  | 1  | 1  | 1   | 1   | 3  | NC               |
| Oil cooler         | Fan                     | 5  | 2  | 7  | 1   | 1   | 18 | NC               |
|                    | Terminal blocks         | 1  | 1  | 1  | 1   | 1   | 3  | NC               |
| Hydrostatic        | Indicator Display       | 10 | 2  | 7  | 1   | 1   | 28 | NC               |
| cooler X/Z         |                         |    |    |    |     |     |   |                  |
| Engine and drives  |                         |    |    |    |     |     |   |                  |
| Protections and    |                         |    |    |    |     |     |   |                  |
| guards             | Seats X, Z              | 8  | 2  | 7  | 1   | 1   | 24 | NC               |
|                    | Ram and rotary tool drive | 8 | 4  | 4  | 1   | 1   | 37 | SC               |
|                    | Windows                 | 8  | 2  | 4  | 2   | 1   | 22 | NC               |
|                    | External housing        | 8  | 4  | 4  | 2   | 1   | 38 | SC               |
| Barron             |                         |    |    |    |     |     |   |                  |
|                    | Terminal release piston | 8  | 2  | 7  | 1   | 1   | 24 | NC               |
|                    | Automatic tool changer  | 8  | 2  | 7  | 1   | 1   | 24 | NC               |
|                    | Turret                  | 8  | 2  | 7  | 1   | 1   | 24 | NC               |


### 3.3.3. Maintenance Schedule

Once the maintenance activities have been established, they are classified according to their frequency of performance in three groups: quarterly, half-yearly and annually. They are also grouped according to the employee profile needed for the development of the task: mechanical worker, electrical worker and operator. These activities are scheduled in the maintenance software, which is called "Central", which license has been acquired by the company. This software allows the monitoring of maintenance orders generated for the machine. The maintenance plan is structured with preventive maintenance activities and the software database allows the analysis of a statistical analysis of the failure components which in the future will allow the development of predictive maintenance studies. Corrective maintenance activities must be uploaded in the same software.

### 3.4. Safety, health and environment

The owner company of the center had already implemented practices of environmental care, industrial safety and occupational health certified and standardized by international standards. However, for this machine, it is specified as a special environmental control. It has been established that the cutting liquid (normally soluble oil) must be biostable and that the good condition of the machining surfaces and the longevity of the tools are ensured. Regarding industrial safety, improvements have been suggested in the development of this practice, mainly for control and supervision.

For the manipulation of mechanical components or tools, the operator will be provided with industrial gloves to prevent injuries to the hands and safety boots to protect the feet against falling parts or tools. For parts or tools weighing more than 10 kg, it may be necessary to use lifting equipment. Periodically,

| Component          | Object            | Criticality status | Criticality status |
|---------------------|-------------------|--------------------|--------------------|
|                     |                   | IP     | FO    | CM    | SAH   | FFF    | C     | Criticality |
| Main structure      | Baseplate         | 10     | 4     | 10    | 2     | 1      | 52    | 52   | C          |
|                     | Plate             | 10     | 4     | 10    | 1     | 1      | 51    | 51   | C          |
|                     | Columns - Gateway | 10     | 4     | 10    | 2     | 1      | 52    | 52   | C          |
|                     | Moving parts      | 10     | 4     | 7     | 1     | 1      | 48    | 48   | SC         |
|                     | Chips protractor  | 5      | 2     | 7     | 1     | 1      | 18    | 18   | NC         |
|                     | Electric engines  | 10     | 2     | 7     | 1     | 1      | 28    | 28   | NC         |
|                     | Slide X           | 10     | 4     | 7     | 1     | 1      | 48    | 48   | SC         |
|                     | Rotary tool drive | 10     | 4     | 10    | 1     | 1      | 51    | 51   | C          |
|                     | Tooling           | 8      | 4     | 10    | 1     | 1      | 43    | 43   | NC         |
|                     | Tool case         | 8      | 2     | 10    | 11    | 1      | 37    | 37   | SC         |
|                     | Chip conveyor     | 8      | 2     | 7     | 1     | 1      | 24    | 24   | NC         |
| pneumatic system    | Air               | 10     | 1     | 1     | 1     | 1      | 12    | 12   | NC         |
|                     | Valve             | 8      | 2     | 7     | 1     | 1      | 24    | 24   | NC         |
|                     | Filter            | 8      | 2     | 7     | 1     | 2      | 24    | 48   | C          |
| hydraulic system    | Pipe              | 8      | 2     | 4     | 1     | 1      | 21    | 21   | NC         |
|                     | Hydraulic reservoir| 10    | 2     | 7     | 1     | 1      | 28    | 28   | NC         |
|                     | Cooling pump      | 8      | 2     | 4     | 1     | 1      | 21    | 21   | NC         |
|                     | Hydraulic central | 10     | 2     | 10    | 1     | 1      | 31    | 31   | NC         |
|                     | Pressure-reducing valves | 8 | 2 | 7 | 1 | 1 | 24 | 24 | NC |
|                     | Hydraulic fluid   | 8      | 2     | 4     | 1     | 2      | 21    | 42   | C          |
|                     | Oil filter        | 5      | 2     | 4     | 1     | 2      | 15    | 30   | SC         |
|                     | Accumulator       | 5      | 2     | 4     | 1     | 1      | 15    | 15   | NC         |
|                     | Warehousing       | 5      | 2     | 4     | 1     | 1      | 15    | 15   | NC         |
|                     | Tubes             | 5      | 2     | 4     | 1     | 1      | 15    | 15   | NC         |
|                     | Filter            | 5      | 2     | 4     | 1     | 2      | 15    | 30   | SC         |
|                     |                   | **Criticality average** | 1.1 | 23.5 | 24.8 |
all operator protection systems such as windows, railings, doors, and safety locks must be checked. To preserve the safety and health of the operator, it is necessary to equip him with personal protection elements and make sure that he wears them to prevent her physical integrity and health. Standardized signage of prohibition, warning, safety and information is used when carrying out the different machining and handling processes on the lathe, in order to identify and anticipate risks based on the NTE INEN 439: 1984.

Even though the noise emission perceptible from the operator’s workstation reaches values allowed by ergonomics according to the respective manual. The operator must be provided with hearing protection as these values may vary depending on the material and the speed at which it is operating. As for the lighting arranged in the control area (inside the elevator), it is higher than 500 lux. Besides, several rows of LEDs are used to illuminate the machine located on the roof of the main pavilion. All this means that there are no ergonomic problems in the workers’ area. The operator must maintain a minimum distance of 500 mm from the transparent windows. The use of certain substances such as aluminum or magnesium can cause additional fire hazards and inhalation of harmful dust. Machining unbalanced parts can create a projection hazard. The means to minimize risks are balancing the part or machining at reduced speeds. The guards provided by the machine are also used to minimize the risks of projections, but they do not eliminate them. In the electrical cabinet there may be hot areas that should be avoided touching. In the case of updating or changing administration software, it must be verified that all the security systems that have been managed are activated. Some of the safety systems are the reduced speed of the axes, the safe stop and the adjustment mode, among the main ones. Figure 5 shows the signage implemented in the machine.

3.5. Overall Equipment Effectiveness

Once all these improvements had been implemented, a calculation of the overall equipment effectiveness and improvements in the production system was developed. This analysis is based on a 100% perfect theoretical score in three categories: availability, performance and quality. These percentages are affected by 6 typical big losses.

4. Experimental results

To compare the OEE before and after the implementation of TPM we will compare the repair of the upper cover of a Francis turbine of a hydroelectric plant. 2 different upper covers were repaired one before the implementation and another after the implementation. This repair was planned to be delivered in 16 days and 10 hours from the moment of arrival of the cover to the center until delivery to the owners. In Figure 6 you can see a contrast of the changes that were obtained in the calculation of the OEE before and after the application of this proposal.

Figure 5. Implementation of standardized signage.
OEE = Availability * Performance * Quality
Availability (A) = (Available Time – Unplanned Downtime) / Available Time
Performance (P) = (Total Production Parts/Operating Time) /Idle run rate
Quality (Q) = (Total Produced Parts–Defects Parts) / Total Produced Parts

4.1. Analysis before and after TPM implementation
Before:
Availability = 90/144 x 100=62.5%
Performance = (1)/(1.07) x 100=68%
Quality Rate = (1)/(1) x 100=100%
OEE = 62.5x 68x100% = 58.38%

After:
Availability = 115/144 x 100=79.9%
Performance = (1.02)/(1.07) x 100=95%
Quality Rate = (1)/(1) x 100=100%
OEE = 62.5x 68x100% = 75.9%

![O.E.E.](image)

Figure 6. Interpretation of the OEE before and after implementation.

5. Conclusions
The physical structure of the vertical lathe was carefully reviewed, allowing an analysis of the functions of each system, subsystem, component and part. This made it possible to distinguish between the objects that can be maintained by their workers of the maintenance team with the application of preventive and predictive maintenance (called maintainable) and those parts that cannot. This proposal allowed maintenance personnel to focus on preserving certain elements of the machine, whose functions and costs are representative of the different production areas of the company. The application of the 5S methodology made it possible to improve working conditions for operators, which represents the basis of this proposal. At the same time, some suggestions were implemented for improving the environmental conditions control and industrial safety, which reduces the probability of incidence of work accidents. After defining all the maintainable elements, by the FMEA analysis, it has been determined that 77 of the 192 lathe components (44.10%) are classified as having a high risk of failure. According to this, it is concluded that objects with an RPN higher than 52 are mostly found in the hydraulic system (pumps and filters).
The maintenance activities were structured in maintenance ranges separated by their type and frequency of application. This allowed managing the time scheduled for maintenance or for production on the equipment. By using a specialized software in maintenance, the maintenance plan to be developed by the operators has been managed in a better way. Finally, the OEE comparison before and after the implementation of TPM demonstrated that was a positive impact on the OEE of the lathe.

This research is a pilot project, which could be implemented throughout the full laboratory and therefore the authors of this work propose to do it in the future. However, this investigation has been tested in real industrial equipment demonstrating the benefits of its appliance therefore, it can be replicated in other companies and other fields of the industry.

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