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Improving Preventive Maintenance Management in an Energy Solutions Company

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Abstract

In industry, production processes and assets are constantly evolving, Thus, continually improving and updating them is essential to their sustainability. This work intended to apply a set of methods and philosophies to improve the Preventive Maintenance Management process in a case study company dedicated to the development, production and maintenance of power and distribution transformers. Thus, a Action – Research methodology was used. After identifying the main problems, a mixed maintenance strategy based on Reliability Centered Maintenance (RCM) and Total Productive Maintenance (TPM) was applied. The following achievements were obtained by this work: (a) method of grading equipment critically based on its importance to the production process was developed and implemented;(b) a new flowchart of decisions and actions was developed for Preventive Maintenance Plan Management; (c) a reduction of the waste time in Preventive Maintenance (PM) was obtained; (d) the implementation of Autonomous Maintenance (AM) resulted in a reduction of 66% in equipment failures; (e) a set of new Key Performance Indicators (KPI´s) were introduced; (f) maintenance plans compliance rates increased by 12%. At the end of the work a reduction of € 120 060 could be achieved. Thus, the main contribution of this work was to show that bringing to the action different tool together in an organized way and share the information and responsibilities with the workers can result in important savings to the company, becoming the maintenance function more effective.

Keywords: Equipment Criticality, TPM, RCM, Autonomous Maintenance, Preventive Maintenance, Performance Indicators, Waste of Time, Power transformers.

1. Introduction

In the 21st century, competitiveness and innovative capabilities are key factors for a company to succeed. Constant technological developments and industrial competitiveness create the need for the companies to have the ability to adapt to changing and evolving markets. Competitiveness is based on an integrated management industry, with teamwork across sectors, that all converge to the same purpose [1. Industries focus primarily on production and everything around it (customers, needs, resources, political and social context) in order to optimize operational efficiency, quality and productivity.

The need for the Maintenance function to keep up with the constant changes and complexities of the industrial system requires the Maintenance is solidly structured and properly planned [2]. Thus, new methodologies for Industrial Maintenance Management emerge as a solution to improve its performance [1,2]. This work was developed in that context.

The development of this work arises from the need of a company to implement new methodologies and tools in its maintenance management function and have greater control over the

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plans compliance rates, as well as the preventive maintenance assertiveness. Thus, the present work deals with the restructuring of the Preventive Maintenance Records of machines and equipment, the maintenance planning management alignment with the production, as well as the implementation of maintenance performance measurement tools.

In order to conduct this work, the Action – Research methodology was selected, divided into five items: (1) data gathering and analysis for diagnosing the problems; (2) action planning - defining corrective actions; (3) actions are enforced based on the plans made in the previous stage; (4) implementation stage and evaluation of the outcomes; (5) monitoring and standardizing the procedures implemented.

This work is divided into five Sections, starting by this one where a contextualization is performed. Section 2 provides the theoretical support to the development. Section 3 describes the methodology adopted. Section 4 refers to the results achieved, Section 5 discuss the results and Section 6 highlights the main contributions and limitations of this work.

2. Literature review

The maintenance main responsibility is to provide a service that enables an organization to achieve its objectives [3], assuming that one of the priority objectives is to maximize equipment availability [4,5]. Over the years, the importance of maintenance, and consequently all the necessary management, has been changing, assuming an increasingly important role in organizations, such as ensuring the availability of assets and facilities, highlighting the optimization of reliability, costs and safety [6]. From a management standpoint, there is a need to distinguish whether maintenance work is planned or unplanned. The planned maintenance consists of works that anticipate possible breakdowns, ensuring a higher availability of equipment, thus, tasks need to be performed in advance, as well as the necessary spare parts in order to affect the production as little as possible. This type of maintenance implies greater control of assets and capacity. Unplanned work refers to unforeseen situations, does not involve any planning or preparation, and execution will be dogged by the nature of the situation [7].

Currently, there are several nomenclatures associated to the maintenance function, as well as maintenance models. Thus, it is important to know the characteristics and approach of each model [4, 8]. Today, with increasing global competitiveness, the focus is on maximizing asset effectiveness, minimizing failures and maximizing gains [1]. Thus, new challenges arise for maintenance management, such as: risk management; human reliability; accuracy in measuring and demonstrating results. Maintenance performance indicators measure the outcome of activities, using resources to maintain an asset, or restore it to a state where performance is desired for the function. Therefore, they should be able to show improvement hypotheses and enable analysis to detect the problem that may cause inefficiency and to assist in solving the problem [9-11].

The maintenance strategy involves ensuring technicians with the necessary skills; make proper preparation of work and information management; ensure the necessary tools for the proper execution of tasks; comply with maintenance plans. Planning is the activity of planning maintenance actions (inspections, replacements and repairs) [12].

Total Productive Maintenance (TPM) is a philosophy that involves the full participation of all levels of the organization, aiming to maximize equipment effectiveness and establish a complete preventive maintenance system, using various techniques, some of which are universal, such as 6Sigma, Pareto's analysis and Ishikawa's diagrams, and other concepts and tools such as SMED (Single Minute Exchange of Die), Poka Yoke, OEE (Overall Equipment Effectiveness), and the 5S [13-16].

Reliability Centered Maintenance (RCM) is a strategy whose main goals are to reduce costs, increase the reliability of assets and to make organizations aware of the level of risk of malfunctions they face. It is a structured process designed to develop an efficient and assertive maintenance plan to minimize the occurrence of failure, while considering environmental, safety, operational and cost-benefit factors [1,17-19].

Lean maintenance is a prerequisite for the success of a Lean organization. It can be defined as a proactive maintenance operation that involves planning and scheduling maintenance activities by qualified teams that promote autonomous maintenance, training and skill development and continuous improvement [20-23].

Santos et al. [1] focused on the classification of the assets' criticality, allowing the establishment of more assertive policies in the definition of the spare-parts stock, leading to important savings in one hand, and creating a safe stock of critical parts in the other hand. This is one of the main targets of present work. Ferreira et al. [10] developed two new KPIs (Key Performance Indicators) regarding the Maintenance function, the Reactive-Proactive Index and the Maintenance-Production Index, whose can be used in a matrix that allow evaluating the relations between reactive and proactive maintenance operations, as well as the maintenance workload related to the volume of production carried out by the company. This allows to understand if the maintenance function in a company is in the range of the expected values. Although BS EN 15341:2007 have defined a huge set of KPIs regarding the maintenance function, there are specific needs which imply the development of specific KPIs. Moreover, maintenance function usually interferes with production performance. Thus, improvements in the maintenance usually results in an increased production performance. This is usually evaluated through the OEE value. In this way, Lean tools have been used to increase the availability of the equipment. Guariente et al. [2] used autonomous maintenance to increase the OEE, finding that the implementation of this tool allowed an improved of the OEE by 8%. Otherwise, Pinto et al. [4] already improved the maintenance operations with impact in the production sector by applying SMED methodologies in some specific machines and reorganizing the storage of spare-parts, achieving savings by 12% in the setup times. The implementation of 5S and SMED tools together allowed an increase in equipment availability, rising the OEE index to values above 90%. Thus, it can be observed that organizational improvements can be easily achieved through Lean tools, increasing the performance of the companies.

3. Methodology

As previously described, the methodology used in this work was the Action-Research. Thus, the first step was to proceed to data gathering and analysis for diagnosing the problems (Section 3.1 to 3.4). After that, the actions planned are described in Section 3.5. The remaining steps are shown in the Results.

3.1. Company brief characterization

The study was carried out in a company consisting of one service center and three production centers. These centers integrate the process of fabrication of some components, assembly, drying, oil treatment and transformer repair, motor repair, as well as the storage of raw materials and components. A total of 655 equipment is allocated to the three production centers, such as magnetic sheet cutting machine, Araldite® casting plant, drying and filling plant, CNC milling machine, card milling and beveling machines and winders. The service center is a business unit that provides services on its own equipment or to third-party equipment, such as transformer repair, rotating machinery, facilities and asset management. This unit has about 277 equipment, of which the following stand out: oil treatment and filling units; rotor calibration machine and vacuum groups.

3.2. Maintenance characterization – internal analysis

In the Industrial Maintenance Department (IDM) new challenges arose, such as implementing a preventive maintenance system with greater coverage, assertiveness and effectiveness, covering people, production, processes and information. In the beginning of this work, maintenance managers, together with staff members, assessed the weaknesses of their internal processes through brainstorming, identifying obvious problems and gathering input from production departments. The main problems found entail overworking of inventory in the replacement material warehouse and cost control difficulties, as well as misreading of the performance indicators to be evaluated. Prior to this work, cost control of the maintenance actions was based on an annual previously stablished budget. Despite being a conventional, non-discriminatory method, it did not allow tracking the origin of costs. Maintenance planning synchronization with production, causing difficulties in planning and compliance with the preventive maintenance plan was also identified as a difficulty to overcome. The main issues identified in the IDM are summarized in Table 1.

3.3. Maintenance function performance analysis

In order to complement the previous analysis, some of the indicators that help to identify problems and prioritize areas or departments of production to intervene were studied. One of these indicators is the number of failures in the production centers which is very high, exceeding hundreds, comparing data from 2016 and 2017 years (see Table 2). Moreover, an ascending trend in the number of failures is also detectable.

Table 1. Summary of the main problems of the IDM

Area	**Description**
Management / Planning	Lack of understanding with production;
	Lack of staff to perform the tasks;
	Lack of updated equipment registration.
Performance indicators	Lack of data for results analysis.
Preventive Maintenance Planning	Outdated maintenance plan;
	Preventive Maintenance Records poorly detailed;
	Lack of definition and accountability of the PMP (Preventive Maintenance Plan) process;
	Maintenance time maladjusted.

Table 2. Total failures in productions centers

Production centers	Total Failures (2016)	Total Failures (2017)
Power transformers (PT)	523	637
Distribution Transformers (DT)	1112	1136

The Preventive Maintenance Plan (PMP) compliance rate from January to December 2017 averages 82%, clearly below the target set at 95%. In the DT that objective has been met, but in PT and service center have lower rates than desired, 75% and 85% respectively.

3.4. Preventive maintenance performance times analysis

In order to understand the assertiveness of the Preventive Maintenance Records (PMR), a follow-up was made to the workers, in order to realize the points where the plans could be improved. From these observations, occurrences were recorded as: lost time searching for support material, which forced the technicians to stop; lack of preparation for the needed materials (spare-parts); unplanned work; technicians only know the tasks in the morning of the working day; lack of estimates of maintenance duration; lack of performance indicators; mismatch tools for the task; coordination between technicians.

3.5. Lack in asset identification

In order to obtain a systematic differentiation of the equipment, it was necessary to develop a formulation of an internal methodology for the classification of the criticality of the equipment, in the initial operational scenario. The methodology is based on a qualitative analysis technique, however, whenever possible they were aided by a quantitative technique. It should be noted that the whole process of defining the criticality of the equipment was developed by a multidisciplinary team consisting of the Maintenance, Engineering, Production and Quality, Environment and Safety (QES) departments. The analysis of the equipment criticality data becomes important for the definition of the assets and production centers to be analyzed in more detail, in order to improve the performance indexes.

3.6. Approach to Improvement Actions: Brainstorming

After the identification of the main problems to be worked out, considering the availability and reliability of the data obtained, brainstorming sessions were carried out in order to determine the possible actions to be implemented in order to solve the problems. After a deep analysis, possible solutions were listed as shown in Table 3. From the analysis of Table 3, it can be concluded that most of the improvement actions are related to processes restructuration and information of the maintenance function. This restructuration must be linked in parallel with management and planning, so that it results in a more effective, efficient and assertive day-to-day activity of the technical team, resulting in positive and quantifiable results.

Table 3. Summary of possible solutions as result of brainstorming sessions

Area	Possible solutions
Management / Planning	Establish a method of coordination with production planning;
	Create and train a team able to assist in the execution of preventive tasks;
	Establish a well-defined preventive plan to support a planned corrective action plan.
Performance indicators	Create more reliable information sources.
Preventive Maintenance Plan (PMP)	PMP review;
	Optimize and plan PMPs to increase the availability of technical staff or, if necessary, to outsource technicians;
	Implementation of Autonomous Maintenance (AM);
	Control and management of anomalies found in preventive maintenance (PM).

4. Results

Based on the identification of problems initially carried out, the development of actions to enable the achievement of the recommended objectives was initiated. Critical assets identification was the first step, followed by the proper management of the Preventive Maintenance Plan, creation of Autonomous Maintenance sheets, review of the Preventive Maintenance Records, control of the anomalies found out in the PM, development of KPIs and Maintenance Costs Control.

4.1. Critical assets identification

Asset classification was divided into three classes, class 1, class 2 and class 3, according to the criteria previously analyzed. Class 1 refers to equipment that directly affects product quality, involves high risks to the safety of personnel or the environment, class 2 refers to assets that indirectly affect product quality, or partially disrupt production, as well as present risks of accident, moderate costs and technological complexity, criticality class 3 integrates assets that do not affect product quality, do not cause any safety and environmental risk, do not interrupt production and include low impact costs and technological complexity. Fig. 1 shows the number of assets and their distribution across the three criticality classes.

	1	2	3	TOTAL
DT	22	20	166	208
PT Geral	13	20	47	80
ST	9	35	147	191
CT	13	35	128	176
SRV-VP	1	16	23	40
SRV-VNVG	1	0	146	147
SRV-VS	1	0	89	90
Total	60	126	746	932

Fig. 1. Number and criticality of assets

After this analysis and conclusion of the classification, the team involved in the process agreed with the criticality of the equipment obtained in the results analysis, thus being able to start the next phase, where strategies were defined, in order to prioritize the assets according to their characteristics.

4.2. Preventive Maintenance Plan management

In order to improve the management of the PMP, the work team prepared a restructuration of the decisions flow and actions to be taken. The main difference to the previous management is that Production Planning (PP) receives in advance, i.e. two weeks in advance, information on assets requiring preventive maintenance and thus provides an early response from the equipment availability. With the new management model, significant improvements were observed in meeting the PMP. The factors that influenced this advance were the implementation of a predefined planning, two weeks in advance, which allowed an improvement in the management of the technical team, the equipment to be intervened, as well as the convergence with the availability of assets with the production planning.

4.3. Autonomous Maintenance Sheets (AMS) creation

After analyzing the number of failures, the team decided to implement the TPM Autonomous Maintenance (AM) tool, in assets with a higher criticality level. A set of 43 equipment were selected. For this purpose, maintenance sheets were prepared, which describe the procedures to be performed in these interventions. These will be carried out by the equipment operators, after approval by the QES department, and training provided by the IDM managers. Fig. 2 shows an example of an autonomous maintenance sheet.

With the AM tool, a significant reduction in the number of failures has been achieved in all the assets in which it was implemented. In Fig. 3 it can be checked the failure reduction rate. In two of these equipment's, there was a reduction higher than 50%.

Nº Seq.	Group	Place	Action / Methodology	Means / Tools	IEP*	Stop/ Func.	Photograph
1	Bermaq	Emergency button	Check status and operation of emergency button. If there is any anomaly, request intervention immediately.			F/S	
2	Bermaq	Head	Clean the socket surface of the tool holder cone. Attention: Do not "blow" into the head. "Blow" around the head and wipe the head.	Compressed air gun Cloths Break Cleaner		S	

Fig. 2. Autonomous Maintenance Sheet

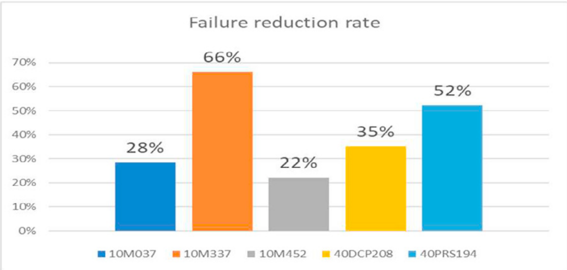

Fig. 3. Reduction rate in the number of corrective interventions after AM implementation

4.4. Review and improvement of Preventive Maintenance Records (PMR)

One of the main problems found out in non-compliance with the PMP was the waste of time and the lack of assertiveness in the execution of PM tasks, as previously referred. Thus, this led to a revision of the inspection plans. The analysis and improvement implementations were devoted to the Class 1 equipment, the most critical class as previously mentioned. Thus, in this section the inspection plans of the criticality equipment were revised. Grounded on that, significant changes were made in 14 procedures and documents, such as:

- Equipment layout rearrangement;
- Revision of the tools needed to perform tasks;
- Materials needed to perform the PM;
- Detailed description of the tasks to be performed;
- Inclusion of estimated times for PM.

After monitoring the technical team, there was a decrease in mean time to repair (MTTR), as well as a significant reduction in waste of time. After analyzing the data, the team involved decided to implement this methodology in the remaining assets of the company.

4.5. Control of anomalies found out in PM

Another improvement opportunity found out was related with control and management of detected anomalies. In order to make a more assertive control of the tasks that are pending as a result of the inspections performed, an application has been developed in MS Excel®. Data feed is done by the person responsible for the PM. This tool includes, among others:

- Asset registration number;
- Production center where the asset is inserted;
- Failure type (electrical, mechanical, lack of cleaning, lack of lubrication);
- Record of anomaly found;
- Criticality of the anomaly;
- An identification of the person responsible for the anomaly resolution.

At the time of anomaly detection, a systematic differentiation of the anomalies must be elaborated. It was necessary to develop an internal methodology for the classification of its criticality. This tool proved to be very useful as it allows for:

- Checking the state of the anomaly resolution;
- Identifying, if applicable, the maintenance operator contacted for resolution;
- Tracking performance metrics such as TTR (Time To Repair), MTTR;
- Defining problem solving responsibilities;
- Checking if the failure is recurrent and proceed with a more detailed analysis of the occurrence.

4.6. Tool developed for KPI analysis and control

In order to address and analyze performance indicators, a tool has been also developed in MS Excel® (Fig. 4) which is aimed at controlling: the rate of compliance with the preventive maintenance plan; the emergency breakdown rate and corrective maintenance rate against the planned maintenance rate. Note that the tool is still under development and in the process of improvement.

The sheet of Fig. 4 is completed at the end of the shift, together with the technicians, to record the interventions performed and the times of each one. After the daily record of the metrics, the next day's planning is elaborated. This includes planned preventive maintenance in green, planned corrective maintenance in blue, and emergency corrective maintenance in red. With this tool it is possible to control and analyze the indicator of compliance rate of the daily preventive maintenance plan; the number of interventions performed compared to the planned number; and the daily corrective maintenance rate (represents the number of failures occurred in relation to the total number of maintenances performed).

Fig. 4. Daily intervention planning sheet

After the restructuring of IMD, cost control with outsourcing appears as a new indicator to study, in order to justify the strategy adopted. It should be noted that the cost reduction strategy is efficient but requires a wide availability of interaction across the IDM. New management methods are being implemented, such as:

- Interventions planning with outsourcing;
- Partner's availability;
- Training plan for the teams;
- Number of people required to perform daily tasks to meet PMP.

4.7. Maintenance function cost control

An asset hierarchy by equipment was introduced. With the implementation of the asset hierarchy, Fig. 5, it is now possible to control the equipment with the highest costs, in order to study the origin of these results. As it can be seen, it is possible to analyze the top five equipment with higher maintenance costs. In 2018, the equipment with the highest cost was 10M022, Pads Air Transport PT Equipment, with € 62 144. In order to understand the origin of the costs, an analysis was made to the top five detected anomalies. This analysis, presented in Fig. 6, allowed to record the type of cost associated with each equipment, for further improvement of this indicator. In this particular case, it was found that the main source of the expenses was related to the materials, with a total cost of € 50 524.

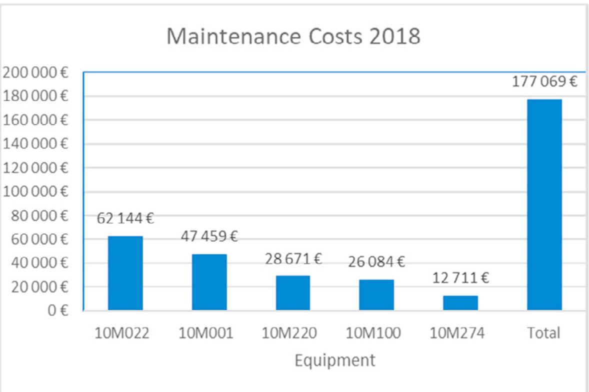

Fig. 5. Top 5 Equipment Costs

With regard to financial indicators, with the improvement actions applied, cost reductions were expected. In Fig. 7 it can be seen the evolution of the maintenance costs before (2017) and after (2018) the implementation of the improvement actions, resulting in a decrease of € 120 060.

5. Discussion

The maintenance function implies enormous coordination with the production function, as is also mentioned by other authors [1,4,6,10], requiring a high organizational effort in order to accomplish with this regard.

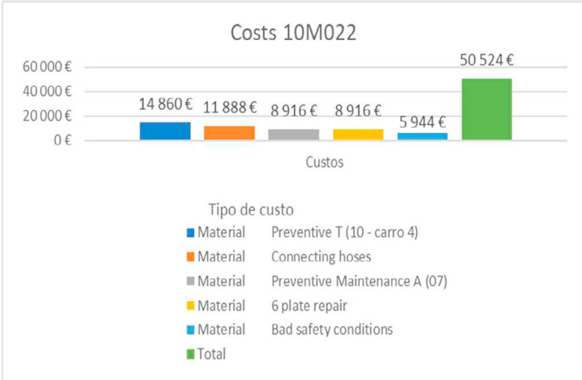

Fig. 6. TOP 5 of the costliest equipment detected anomalies

It is worth to note that the wide diversity of equipment and facilities, as well as production processes, make it difficult to prioritize PMP management, depending on the type or introduction of new products; working hours; production times; the criticality of the assets in constant changing. As a result, maintenance management is subject to constant review and adaptation.

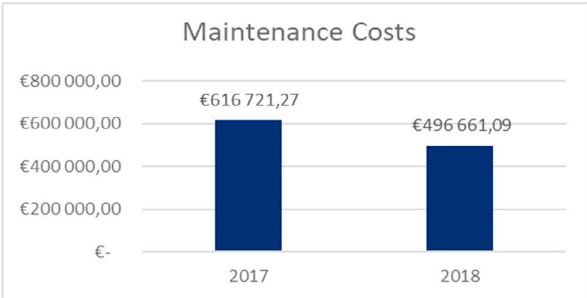

Fig. 7. Maintenance costs

As referred by Santos et al. [1], one of the first improvements to do is to know in depth the assets available in the company and this was one of the first priorities of this work. Then, and as mentioned by Ferreira et al. [10], it is necessary to establish the criticality of the equipment, as only with this information it is possible to redefine the stocks of spare parts and optimize the replacement of components, thus avoiding prolonged stoppages in production. After these first steps, it is necessary to use some Lean tools to proceed with the elimination of waste, which are often linked to organizational factors. These tools were also successfully applied by Pinto et al. [4], Moreira et al. [6], Reis et al. [5] and Neves et al. [13] in other industrial sectors, also quite successfully. Tools such as 5S, SMED, among others, can bring immediate gains to organizations [24]. The implementation of preventive maintenance usually brings strong benefits to the companies and, if possible, the maintenance should evolve to autonomous maintenance, as referred by Guariente et al. [2].

One of the last improvements to be implemented is the control systems. For this to be possible, it is necessary that the information is collected carefully, and later treated in the most convenient way. The best control mechanisms are KPIs, generic or specific, which allow to quickly and efficiently assess the partial and global functioning of a sector such as maintenance, as mentioned by Ferreira et al. [10]. However, it is also necessary to permanently evaluate the combination of efforts between maintenance and production and, for this, the indication OEE is extremely reliable, as reported by Pinto et al. [4] and Rosa et al. [19], even being mandatory in companies certified in the manufacture of components for the automotive industry. Standardizing methodology for addressing problems and action procedures are also extremely important, as was also mentioned in the works presented by Rosa et al. [25] and by Antoniolli et al. [26]. To this end, it is extremely useful to implement PDCA cycles [25] so that these procedures can also be improved on a permanent basis.

6. Conclusions, Limitations and Outlook

The development of this work aimed at the overall improvement of the PMP, with the introduction of improvement tools, in order to ensure greater availability of equipment, as well as reduction of wastes associated with maintenance function.

Table 4 summarizes the main solutions adopted and results of their implementation. In this work, TPM and RCM methodologies strategies were adopted, since both aim to contribute to improving Maintenance Management, ensuring the best performance of the assets in their operational context.

The implementation of preventive maintenance, the classification of equipment and its criticality, the reorganization of spare-parts stocks and the combination of maintenance planning taking into account production needs, allowed significant gains in the company where this work was developed, as can be seen in Fig. 7.

The main contribution of this work is in the approach to the problems and the approach methodology used (Action - Research), which proved to be very effective.

6.1. Limitations

During the work, it was verified that the application of methods and philosophies is not so linear as it seems at first. Each organization has different characteristics, and it is sometimes difficult to define the best strategy to address the identified problems. one of the most important factors for the application of all these theories is the ability to involve all people in the work done, in order to achieve the proposed objectives.

6.2. Outlook: future improvement actions

With the achievement of the proposed objectives, other opportunities for improvement were found, these being fundamental to maintain the good functioning and the tools developed in conditions of being used in the best way. Much of the action involves a continual need to upgrade equipment as well as control of spare parts. Table 5 shows some of these needs and suggestions for improvement.

Table 4. Result of implementing solution proposals

Proposals / Solution	Implementation Results
Equipment Criticality Rating	Criticality rating of all equipment at production centers; Study and critical analysis of the results (Class 1 - 6.6%; Class 2 - 13.6%; Class 3 - 79.8%); Development of an asset management and control tool.
Definition of an asset approach strategy according to criticality	Management strategy to be applied to the three asset classes (1,2 and 3) at production centers.
PMP Management	Restructuring of PMP management; Development of a tool to provide the necessary information to the production centers about the assets, the duration and the days on which the interventions will be carried out; Implementation, training and validation of inspection routines resulting from the new PMR; 12% increase in PM compliance in PT production center; Reduction of waste and MTTR times in the performance of PM, after revision of the PMR; Reduction of failures in assets where the MA were applied, about 50% in two of these equipment's; Development of a tool to control the anomalies found in PM; Classification of criticality of anomalies, as well as new management strategy of criticality classes.
KPI analysis and control	Development of a tool for analysis and control of performance indicators (under development); Cost control with outsourcing staff; Equipment cost control.

Table 5. Suggestions for future improvements

Area	Improvement suggestions
IT management system	Implementation of maintenance management software that enables real-time data removal and root causes to be addressed more efficiently.
Performance indicators	Implement tools such as 3C analysis and FMEA to address identified issues; Implementation of new indicators to measure the assertiveness and efficiency of the maintenance department.
PMP	Implement routines with short periodicity in more critical assets; Holding small meetings with production planning to validate the availability of equipment to perform PM; Increase the number of AM, and verification / validation of its compliance; Team motivation to make them feel like part of the work; Creation of spare parts stock to carry out the interventions.

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