Impact of Autonomous Maintenance on a PIM Production Line

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Abstract

To increase the competitiveness of their products, companies have sought to identify and eliminate losses in their production processes to reduce production costs. One of the six major process losses established by the Total Productive Maintenance (TPM) philosophy is related to equipment downtime in the production environment. This paper analyzes the impacts of the implementation of autonomous maintenance through the eight-step analysis implemented by a project developed in line 3 of the welding sector of a factory located in the city of Manaus, capital of Amazonas, Brazil. To this end, the indicators were evaluated, establishing the solution priority, defining the necessary actions and implementing them. Upon completion of the project, there was a 39% increase in operators' knowledge of machines and autonomous maintenance procedures, as well as a 75% reduction in line equipment downtime, increasing the availability from 94.9% to 98.7%, allowing to verify the effects of the execution of the autonomous maintenance activities.

Keywords: TPM; Autonomous Maintenance; Equipment Availability;

1. Introduction

The most competitive market has led companies to reinforce philosophies or projects that increase the competitiveness of their products through direct and indirect cost analysis, actions that contribute to the quality and productivity indices of manufacturing processes. These two indicators are directly linked to the policies of company X which is the case study of this research.

Company X will thus be designated by the privacy policy of the organization, is a company that operates in the two-wheel pole, located since 1985 in the Industrial District of Manaus. The survey was conducted in 2012 when the company was facing a drop in market share and a significant reduction in annual sales volume. Given this scenario, the Total Productive Maintenance (TPM) philosophy was used to implement projects to identify opportunities and consolidate improvements in production processes through continuous activity planning, resulting in cost savings and optimization of its facilities and facilities. available labor force.

One of the methodologies developed in the TPM philosophy, called Autonomous Maintenance, acts on the diagnosis of equipment conditions, optimizing the skills of employees who operate the machines throughout the production shift. Thus it is possible to identify possible changes in the equipment's operating routine, anomalies that may lead to interruption and consequent production shutdown.

This research focuses on the maintenance sector of Company X, which ended the first half of 2012 with a breakdown rate of around 23% above the target, with a mostly corrective action being observed, with an ineffective preventive plan, which does not have been prioritized by expert maintenance. Besides, there was a lack of predictive planning for equipment, as well as low interaction between the productive and maintenance sectors, making the monitoring of machinery and equipment situation more complicated.

In this sense, the definition of the most critical sector of Company X was based on a survey of downtime due to equipment failures in all sectors of the plant, from July 2011 to June 2012. As illustrated by Figure 1, the welding (Solda) sector was considered the most critical with 43% machine downtime in this period, being this the sector chosen to carry out a pilot test of implementation of an autonomous maintenance project.

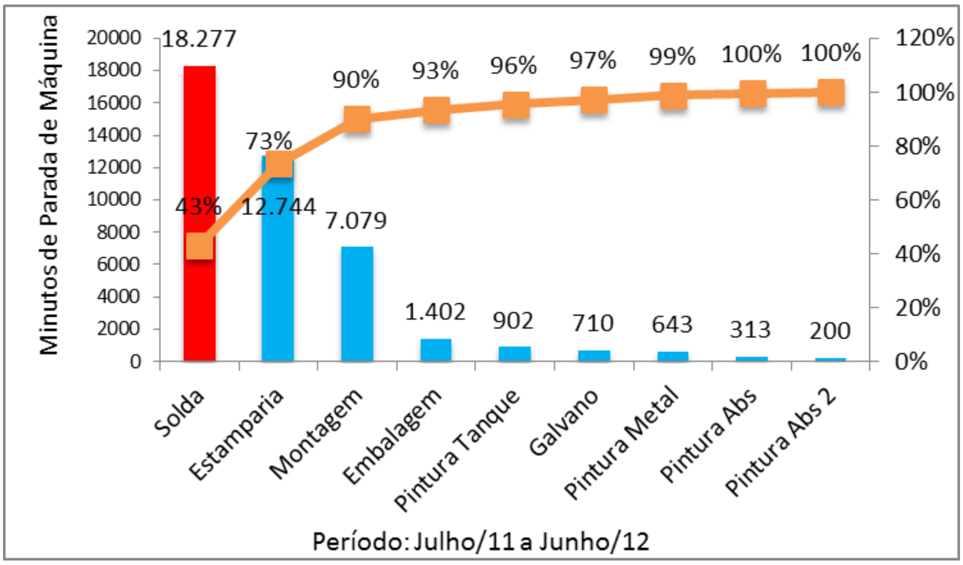

Figure 1 – Machine Downtime per Sector

Source: Company X Maintenance System

Given this context, the general objective of the research is to evaluate the impacts of the implementation of autonomous maintenance in the welding sector of company X.

The research is relevant to the company because of the potential to improve the skills of machine operators, as well as reducing the average downtime on the production line defined as a priority by the pilot project.

Also, it is worth noting that conserving machines, equipment and facilities is a principle that should be seen as a strategic function in achieving the organization's results and should be directed towards supporting management and solving production issues, launching the company at competitive levels of quality and productivity (KARDEC and NASCIF, 2001). Thus, the maintenance policy must be defined by the company according to its organizational objectives, presenting itself as a determining factor of the success of production planning and, therefore, of process productivity (WIREMAN, 1998).

For the academy, research can serve as a study in the classroom, as well as generate discussion and new research for those interested in the subject.

2. Theoretical Referential

Maintenance is a relevant factor to increase productivity and contribute to quality assurance. A high rate of equipment failure leads to production losses, as current inventory policies have eliminated standby products between processes, so any interruption in the manufacturing flow leads to a reduction in the quantity produced.

Kelly (KELLY and HARRIS, 1978; KELLY 1984; 1989) has conducted maintenance studies and consulting for many years and has written books on maintenance function management. This author considers maintenance as the control of reliability, using an approach with the following steps:

1) defining the function of the maintenance system in the enterprise; 2) define the objectives; 3) establish the maintenance strategy; 4) predict how the equipment will be used; 5) define the maintenance workload; 6) indicate the structure of resources, including labor; 7) establish the planning and task control system; 8) establish the influence of the administrative and decision-making system; 9) control maintenance to ensure that the system works to achieve its objectives; 10) establish a documentation system.

Brazilian Standard NBR 5462 (ABNT, 1994) points to maintenance as the combination of all technical and administrative actions, including supervisory actions, designed to maintain or relocate an item to a state in which it may perform a required function.

Moubray (2000) argues that maintenance aims to ensure that physical items continue to do what their users want them to do. According to Smith (2004) maintenance aims to preserve the functional capabilities of the equipment and operating systems.

Maintenance is a branch of engineering that consists of preserving the productive means (machines) that the company owns so that the operation of the process is guaranteed in the parameters of lean production and does not influence the deadlines of meeting the demand. Performing maintenance activities means acting in a preventive and non-corrective manner (BRANCO, 2008).

This article will be based on the maintenance concept defended by Gusmão (2003), as the set of activities aimed at ensuring, at the lowest possible cost, the maximum availability of equipment for production, at its maximum capacity, preventing the occurrence of failures, and identifying and solving the causes of poor equipment performance.

2.1 Maintenance Evolution

The authors Kardec and Nascif (2001) believe that the maintenance had three stages of development, the first took place before 1940 focused on the failures concert, as the second phase took place between 1940 and 1970 focused on ensuring greater availability of equipment, focused on its life, while the third phase happened after 1970 with the search generate greater availability and reliability of equipment, worrying about the quality of products and the environment.

Slack (1999) reports that until the 50s, productivity was directly affected by the maintenance break, which operated in the correction of production equipment when were defective. However, the need for reliable processes and greater consistency in quality maintenance led to a level of more preventive action, acting in cleanup activities, lubrication, replacement parts, and checks. In the 60s, maintenance activities become predictive, ending the emergency interventions, making it possible to predict the stops machines, adjusting production to avoid lost productivity.

2.2 TPM Philosophy

In pursuit of process optimization, Toyota Motor Company developed in the late twentieth century in Japan a philosophy that aimed at reducing process waste and quality assurance, called Total Productive Maintenance (TPM). One of the focuses of the Japanese technique was to invest more resources in the maintenance area, aiming at reducing the failure rate and downtime of the production line equipment.
According to Suzuki (1994) TPM's objectives were defined by the Japan Institute of Plant Maintenance <https://www.jipm.or.jp/en/>: (a) to maximize the efficiency of production systems; (b) minimize losses by setting targets for zero accidents, zero losses and zero defects throughout the life cycle of the productive elements; (c) involve all departments in deployment, including new products, sales, and administration; (d) involve all employees from senior management to shop floor operators; and (e) act for small group activities.
For Takahashi and Osada (1993), TPM is a company-wide campaign, with the participation of the entire staff, to achieve maximum utilization of existing equipment, using the equipment-oriented management philosophy.
Nakazato (1998) pointed out the three meanings of the word TPM:
a) Total: means the overall efficiency or life cycle of the production system as it aims to constitute a business structure with the maximum efficiency of the production system. It seeks the participation of everyone from senior management to front-line workers, involving all departments, starting with the production department and extending to the development, sales, administration, etc.
b) Productive: seeks the maximum limit of the efficiency of the production system, reaching zero accident, zero defect and zero breaks/failure, ie the elimination of all types of loss. In other words, it does not simply mean the pursuit of productivity, but to achieve true efficiency through zero accidents and zero defects.
c) Maintenance: is the maintenance in the broad sense considering the total life cycle of the production system and defines maintenance that focuses on the single process production system, the factory, and the administrative production system. Maintenance of the production management system means the preservation of this system in its ideal condition through the continuous formation of a business structure capable of surviving the new times through a constant search for the efficiency limit. Maintenance is defined to adapt to changing circumstances.
According to Singh et al. (2013), TPM has eight pillars: pillar 1) individual improvements; pillar 2) autonomous maintenance; pillar 3) planned maintenance; pillar 4) training; pillar 5) initial control of the equipment; pillar 6) quality maintenance; pillar 7) TPM in offices and pillar 8) safety and environment.

2.3 TPM and autonomous maintenance

One of TPM's focuses is autonomous maintenance, whose techniques allow operators to keep equipment in the best possible condition, with only occasional participation from the maintenance and equipment development sector, which only provides operators with support and support in maintenance activities of their machines (GOMES et al., 2012). Autonomous maintenance helps operators maintain their machines, supported by the central maintenance department (TAKAHASHI and OSADA, 2000), which contributes to increasing motivation and commitment to the equipment status of operating teams (GRAISA and AL-

HABAIBEH, 2011).

For Nakajima (1989), the implementation of autonomous maintenance can be performed in the following steps:

Step 1: Initial cleaning to combat dirt sources;

Step 2: Measures to combat problem sources and hard to reach places;

Step 3: Develop inspection standards, lubrication, cleaning, etc .;

Step 4: Inspection to develop operators capable of understanding basic equipment functions, identifying defects and making repairs;

Step 5: Autonomous inspection with a process analysis of inspection, cleaning, lubrication, and retightening activities;

Step 6: organization and order (organization and care of the work environment);

Step 7: Consolidate autonomous maintenance with previous step checks and perform equipment efficiency improvements.

Similar to Nakajima (1989), Imai (1997) proposes 8 steps for implementing autonomous maintenance (Figure 2) ranging from equipment preparation and cleaning to autonomous management, which is the approach to use in this case study.

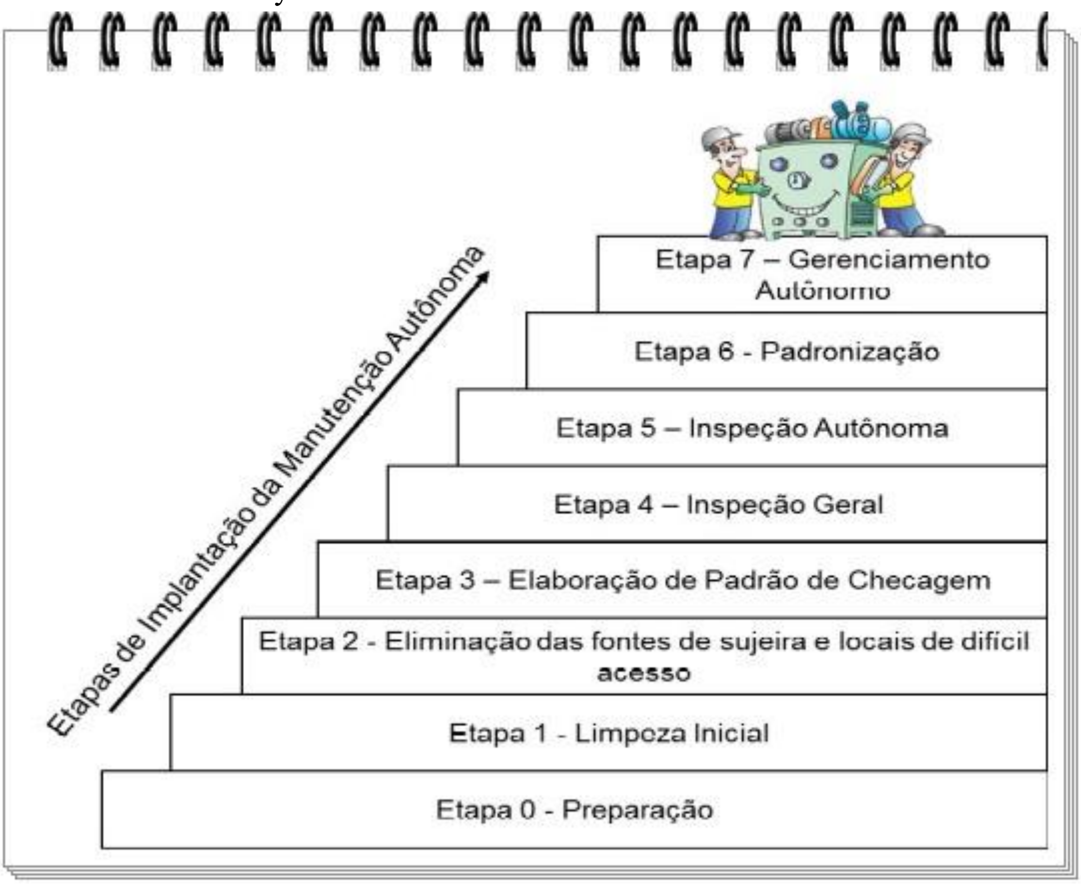

Figure 2 – Autonomous Maintenance Deployment Steps.

Source: Imai (1997).

According to Takahashi and Osada (1993), autonomous maintenance is one of the most effective means of transforming a factory into an equipment-focused operation, providing reliability, availability, productivity, and operational safety characteristics that are important for quality, lead times and production costs.

A case study by Biehl and Sellito (2011) concluded that TPM, and in particular autonomous maintenance, can increase maintenance efficiency as a strategic factor and, consequently, can increase the manufacturing competition of an industrial enterprise.

2.4 Equipament availability

To analyze the impact of equipment on productivity, we use the availability indicator, defined by the percentage of time that a device is available for the performance of its nominal function, i.e. the time that the equipment is available to operate in its fullness, disregarding all the time that it was stopped under the responsibility of the maintenance area.

The analysis time Δt of given equipment can be defined as the sum of the time portion Δt DISP corresponding to the period in which the equipment was available for operation and the time portion Δt INDISP corresponding to the period when the equipment was unavailable. With these two values, the Average Equipment Availability is then defined by the expression (1) below:

$$A\% = \frac{\Delta t_{DISP}}{\Delta t_{DISP} + \Delta t_{INDISP}} \times 100 \quad (1)$$

STEPS	Oct/12	Nov_Dec/12	Jan/13	Feb_Mar/13
Article template presentation	X			
Theme presentation		X		
Introduction: contextualization, problem, justification, objectives, and proposal of the topics for the literature review.		X		
Development: presentation and discussion of the bibliographic review			X	
Data collection and analysis			X	X
Discussion of Results				X
Final Considerations and advisor analysis				X
Essay and review of the article				X
Improvement and delivery the final version				X
Article defense				X

Chart 1 – Research Methodology Schedule.

Source: Author

3. Methodology

The research is applied since the knowledge generated will be used by Company X. Regarding the objectives, the research is descriptive, since it will be described through the variables involved in the sector without interference on them.

Data were collected and analyzed using a combined (qualitative and quantitative) approach through the case study and bibliographic research.

The implementation of the case study happened between july/2012 and feb/2013, but the research started in the second semester of 2012 and was concluded in the first semester of 2013 as part of UFAM Industrial Engineering Course, as described in Chart 1.

Then, the data were digitized and graphed for discussion of results and construction of the article that was defended for an examining board of the Production Engineering course of UFAM's Faculty of Technology.

4. Case Study and Results

4.1 Pilot line definition

The analysis of the impact of autonomous maintenance was performed by collecting data regarding the pilot line defined by company X.

As shown earlier, a large downtime rate was detected in the Welding sector from July 2011 to June 2012. For the same date range, a more stratified data study was performed to define one of the sector production to start the project, as shown in Figure 3:

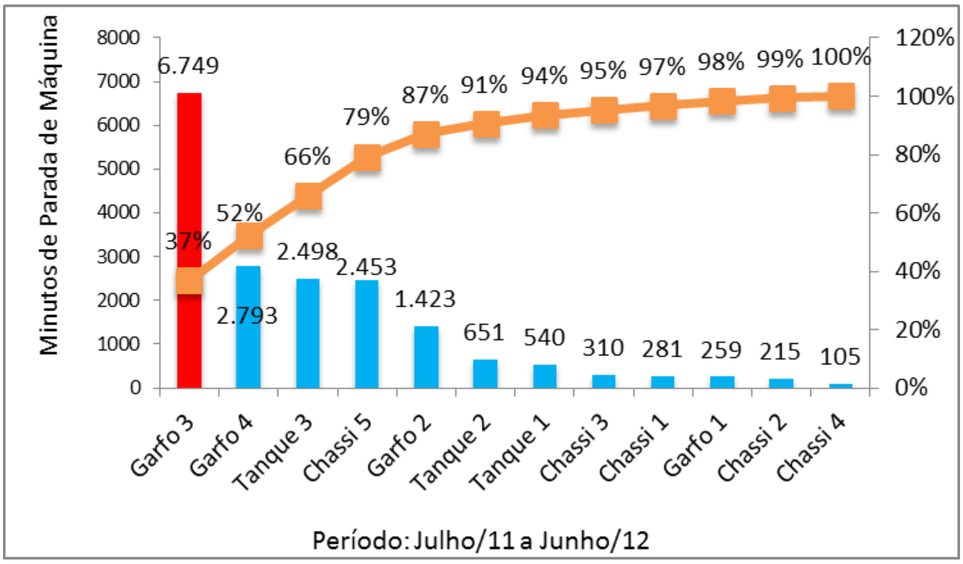

Figure 3 – Machine downtime by production line.

Based on the data collected, it was defined as a priority, the implementation of the autonomous maintenance project in the fork 3 (Garfo 3) line, due to its high rate (37%) of equipment breakdown stops.

After defining the pilot line, the analysis of its structure began. Production operates in the first shift and has 13 operators and the support of a production leader. In all there are 13 machines in the fork 3 line, being 11 MIG welding machines, a CNC machining center, and a boring machine, as follows:

- MIG welding machines: equipment that performs, with the aid of gas, the welding process of the fork parts;
- CNC Machining Center: machine intended for the initial removal of material from the fork through the machining process;
- Boring machine: responsible for completing the machining process, ensuring that the workpiece measurements conform to specification. It is the last stage of the part within the welding industry.

According to Nakazato (1998), it is essential for the success of the project that everyone is involved in the implementation of autonomous maintenance. Based on this, a team was defined for direct activities, consisting of the production, maintenance, engineering, warehouse and production planning, and control sectors.

4.2 Steps for Implementing Autonomous Maintenance

Based on the definition of the project implementation steps, a schedule was prepared for the completion of all activities, starting stage 0 in July 2012, concluding stage 7 in February 2013, totaling 8 months of implementation.

Step 0) Preparation: At this initial moment, the objective was to motivate the team involved, composed of 13 line collaborators, 2 production collaborators, 2 maintenance collaborators, and one engineering collaborator. To this end, instructions were given regarding the purpose of the project, work methodology, implementation steps and operation of the equipment and process. This led to the development of awareness among operators of the need for the TPM system and the importance of performing autonomous maintenance to ensure productivity.

Step 1) Initial cleaning: This was the stage where the first contact was made with the 13 machines, performing total cleaning of dust and dirt, performing lubrication and retightening, and the detection and correction of minor defects. Unnecessary materials were also removed around the equipment, facilitating access to parts. The activities created conditions for the general inspection, raising deficient or broken points for repairs and eventual improvements. The objective was to correct or program the equipment to be repaired to restore its original operating conditions, advising operators on the importance of maintaining the machines in their state of repair.

During the survey of equipment problems, cards were created to signal them. Figure 4 shows the stratification of the problems raised, according to the sector responsible for correcting the irregularity.

LEVANTAMENTO DE CARTÕES AMARELOS			
TOTAL	PRODUÇÃO	MANUTENÇÃO	ENGENHARIA
159	94	62	3

Figure 4 – Number of problems found by sector.

After this study, the activities that remained pending were included in a schedule, following up on the resolutions according to the established deadline.

Step 2) Elimination of sources of dirt and hard to reach places: Refers to the fight against dirt and defects found in the first step. It is necessary to identify all possible points likely to accumulate dirt and to implement defensive measures against dust sources and to prevent spills or leaks. Improvement measures were implemented regarding the difficulty of access to cleaning and inspection areas.

This facilitated cleaning and inspection of equipment, improving maintenance conditions, enabling activities defined to maintain optimal equipment conditions to be part of the operators' routine.

Step 3) Elaboration of verification standard: consists of mapping all machine points that require inspection, retightening, cleaning and lubrication. With this data collected, the check patterns were elaborated to be performed by the operators daily, allowing him to follow the equipment state, detecting any abnormalities.

Also, the standard includes checking, performing lubrication and periodic retightening. Proper execution ensures the three basic components of equipment maintenance: cleaning, lubrication and retightening.

Figure 5 (next page) illustrates the elaboration of the verification standard for the CNC machine, observing the content:

• Check Component: defines the item of the machine that should be undergoing operator intervention;
• Standard: the ideal situation of the checking component;
• Method: establishes the activity that the operator must perform in the checking component;
• Tools: defines the support tools for carrying out the activities described in the method;
• Component illustration: demonstrates by the image the ideal condition of the check component;
• Time: for each autonomous maintenance activity a default execution time is defined, indicated in this field;
• Frequency: the autonomous maintenance intervention should be performed according to the frequency indicated in this field, and could be daily, weekly, monthly or quarterly.

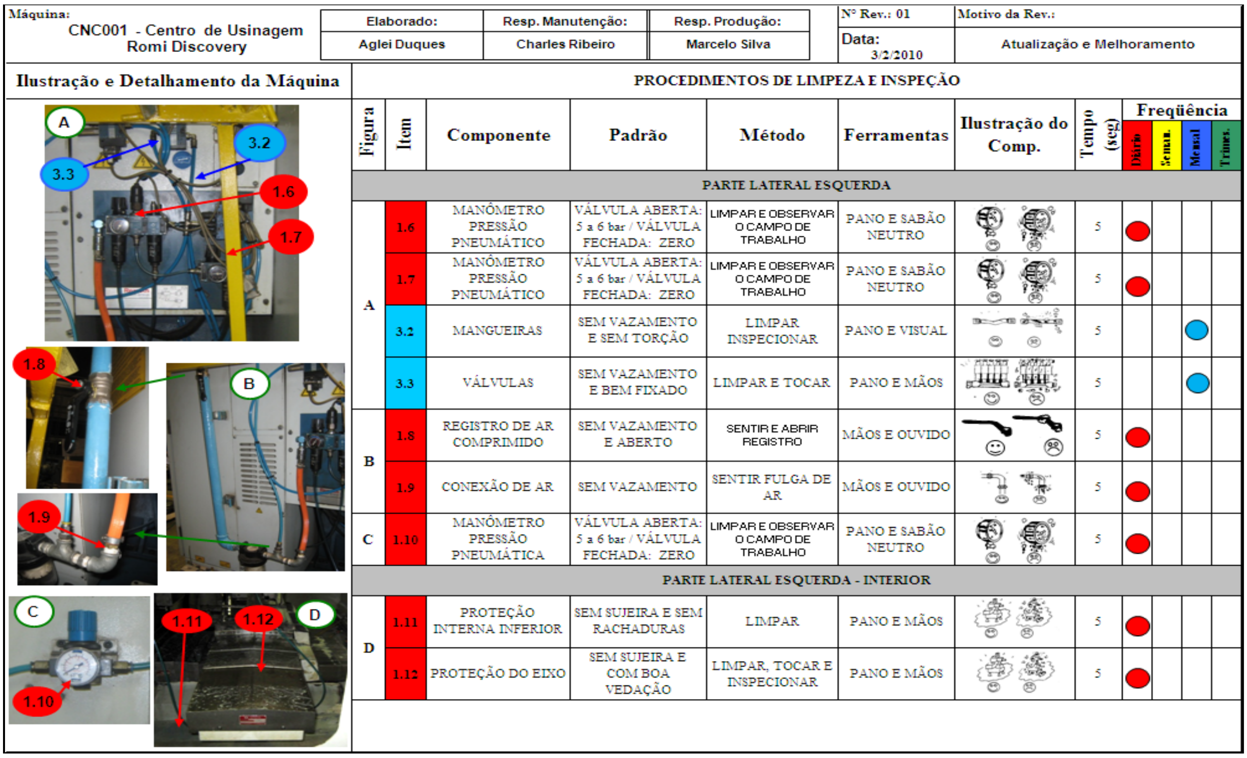

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Ilustração e Detalhamento da Máquina

PROCEDIMENTOS DE LIMPEZA E INSPEÇÃO

Figura	Item	Componente	Padrão	Método	Ferramentas	Ilustração do Comp.	Tempo (seg)	Freqüência: Diário	Seman.	Mensal	Trimes.
PARTE LATERAL ESQUERDA											
A	1.6	MANÔMETRO PRESSÃO PNEUMÁTICO	VÁLVULA ABERTA: 5 a 6 bar / VÁLVULA FECHADA: ZERO	LIMPAR E OBSERVAR O CAMPO DE TRABALHO	PANO E SABÃO NEUTRO		5	●			
A	1.7	MANÔMETRO PRESSÃO PNEUMÁTICO	VÁLVULA ABERTA: 5 a 6 bar / VÁLVULA FECHADA: ZERO	LIMPAR E OBSERVAR O CAMPO DE TRABALHO	PANO E SABÃO NEUTRO		5	●			
A	3.2	MANGUEIRAS	SEM VAZAMENTO E SEM TORÇÃO	LIMPAR INSPECIONAR	PANO E VISUAL		5			●	
A	3.3	VÁLVULAS	SEM VAZAMENTO E BEM FIXADO	LIMPAR E TOCAR	PANO E MÃOS		5			●	
B	1.8	REGISTRO DE AR COMPRIMIDO	SEM VAZAMENTO E ABERTO	SENTIR E ABRIR REGISTRO	MÃOS E OUVIDO		5	●			
B	1.9	CONEXÃO DE AR	SEM VAZAMENTO	SENTIR FULGA DE AR	MÃOS E OUVIDO		5	●			
C	1.10	MANÔMETRO PRESSÃO PNEUMÁTICA	VÁLVULA ABERTA: 5 a 6 bar / VÁLVULA FECHADA: ZERO	LIMPAR E OBSERVAR O CAMPO DE TRABALHO	PANO E SABÃO NEUTRO		5	●			
PARTE LATERAL ESQUERDA - INTERIOR											
D	1.11	PROTEÇÃO INTERNA INFERIOR	SEM SUJEIRA E SEM RACHADURAS	LIMPAR	PANO E MÃOS		5	●			
D	1.12	PROTEÇÃO DO EIXO	SEM SUJEIRA E COM BOA VEDAÇÃO	LIMPAR, TOCAR E INSPECIONAR	PANO E MÃOS		5	●			

Figure 5 – Equipment Check Standard.
Source: Company X

Step 4) General Inspection: conducted 17 training sessions on mechanical, pneumatic, basic electricity, retightening of bolts, belts and chains and general inspection.

The effective qualification of the operators was fundamental for the continuation of the activities since the acquired knowledge will be essential for equipment monitoring and fault detection, besides the small repairs that must be performed correctly, avoiding the aggravation of the situations.

With this knowledge, the checker will have a better foundation for autonomous maintenance.

In this step, the content of the checking standard was revised and training on inspections was reinforced,

assessing the need for items and the frequency of checks, adjusting to the way the operator best adapted.
Step 5) Autonomous Inspection: At this time, the activities performed and the results of the inspections were monitored.
It is important to maintain a cycle of improvements that cover both equipment and process, reviewing forms and visual controls, verifying the need for the activities performed.
In this stage, the operators were internalized for the autonomous maintenance activities, verifying that each one was taking responsibility for their equipment and performing their lubrication, cleaning and inspection activities. The result was obtained by massifying the importance of developing the maintenance performed in the previous stages.
Step 6) Standardization: Given the reviews already undertaken and the follow-up of the activities already achieved, it is time to establish the definitive standards for checking, cleaning, and lubrication. The improvement activities and the operators' autonomous maintenance routine were consolidated in this stage.
Step 7) Autonomous Management: This is the phase to help fix operators with the techniques and skills needed to autonomously perform minor repairs, breakdown data analysis, and machine upgrades.
The main objective of this step is to ensure that the activities become routine of the operators, who will be able to perform the activities autonomously, even after the completion of the implementation project. It was important to make them aware that TPM activities are endless and that improvements must constantly be made so that gains in equipment availability never cease.

4.3 Operator Skills Evolution

Autonomous maintenance focuses on employee accountability for the equipment they operate, working on the qualification of the workforce, providing technical knowledge to ensure the proper execution of the activities described by the TPM methodology.
A knowledge and skills survey was conducted individually with each operator and Figure 6 shows the consolidated evolution of operators' knowledge of machines and autonomous maintenance procedures, comparing the situation before and after the project.
To this end, four levels were evaluated, level A at which the operator becomes able to multiply the skills, level B considered qualified in the skill, level C which only has theoretical knowledge and level D which does not has the needed knowledge about autonomous maintenance.
From Figure 6 it is possible to observe that the two highest levels of knowledge "A" and "B" had an evolution from 52% (Before = 27% + 35%)) to 91% (After = 65% + 26%), showing the effectiveness of the training offered during project development.

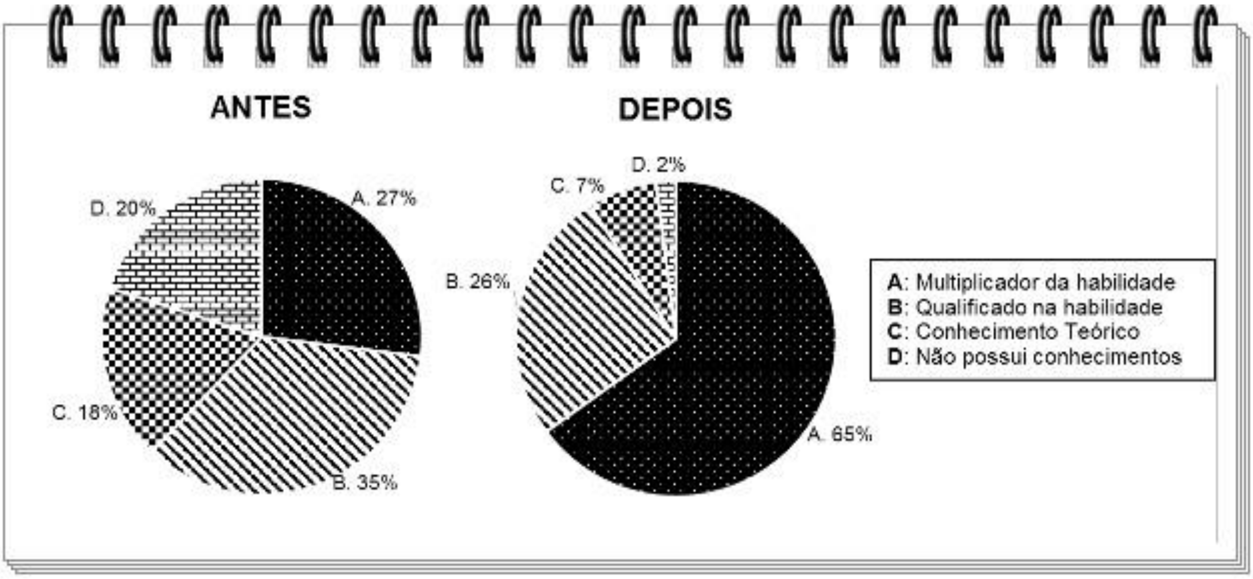

Figure 6 – Operator skills evolution before (antes) and after (depois) project implementation
Source: Author

4.4 Impacts

To assess the impact on the availability of pilot line equipment, a survey was conducted for one year before project implementation, obtaining the following graphical representation for equipment availability (Figure 7).

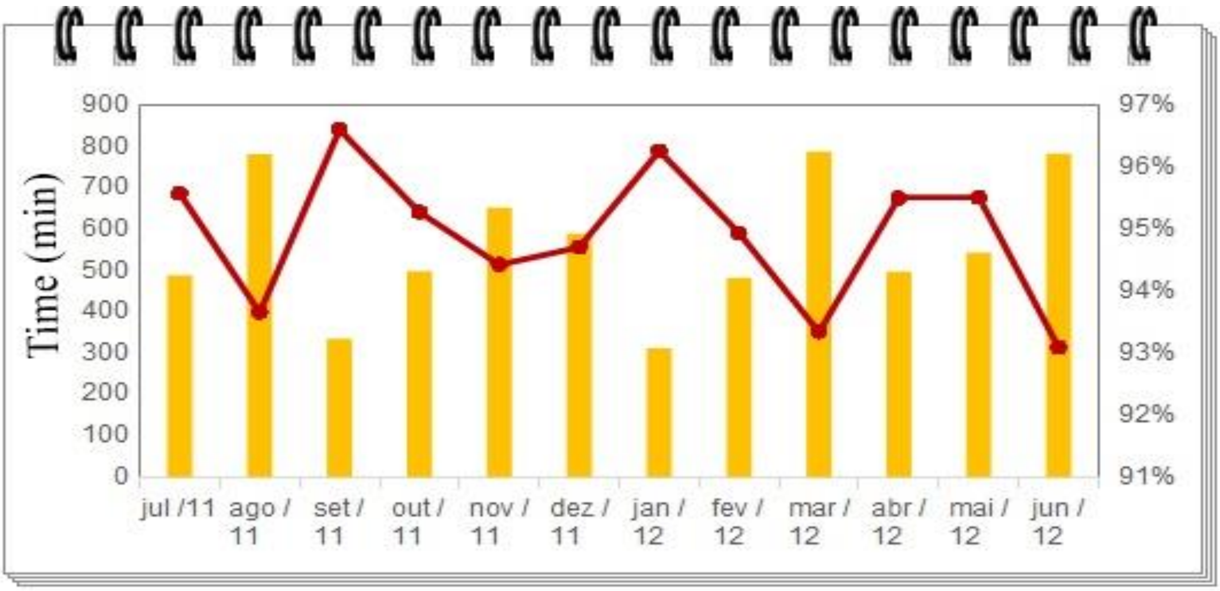

Figure 7 – Line availability index one year before the project.
Source: Author

Then, the same survey was performed for the months after the project implementation began, maintaining the availability calculation formula, as can be seen in Figure 8.

By comparing the data collected about line availability before and after the implementation of autonomous maintenance, it was possible to make a comparison of the monthly availability indicator average, to evaluate the impact of the project implementation.

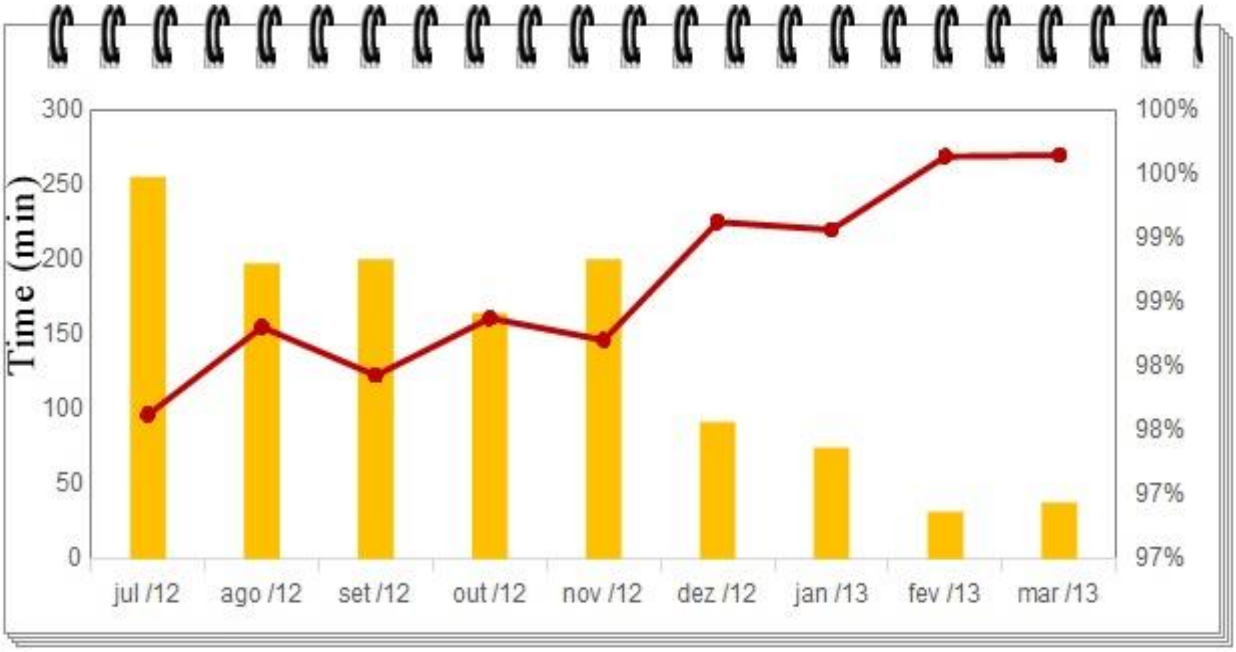

Figure 8 – Availability index after starting the project concerning autonomous maintenance
Source: Author

Figure 9 shows that the average monthly downtime of equipment before the project was 562 minutes, leading to an availability rate of 94.9%, a loss of over 5%.

With the beginning of the implementation of the autonomous maintenance program, there was a reduction in the average monthly downtime to 139 minutes, a decrease of over 75% compared to the previous situation, increasing availability to 98.7%.

Figure 9 – Comparison of equipment availability index
Source: Author

5. Conclusions

The article analyzed the impact of the eight stages of a project developed in fork 3 line in the welding sector in a two-wheel pole factory located in the city of Manaus, capital of Amazonas, Brazil. To this end, the indicators were evaluated, the solution priority established, the necessary actions defined and implemented. Upon completion of the project, there was a 39% increase in operators' knowledge of machines and autonomous maintenance procedures, as well as a 75% reduction in line equipment downtime, increasing the availability from 94.9% to 98.7%, allowing to verify the effects of the execution of the autonomous maintenance activities.

The impact assessment of the implementation of the autonomous maintenance project was released within company X, to share the work developed and encourage the implementation of autonomous maintenance in other areas of the company. New research can be conducted to verify the effectiveness of project results in the sector studied, as well as in other sectors of the company, and also may focus on the level of employee satisfaction with the changes brought about by autonomous maintenance.

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