Research Article

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Implementation of preventive maintenance routines and the "zero breakdowns by base condition" methodology in an organization

Abstract

This work has the general objective of maximizing the availability and reliability of industrial equipment, reducing the frequency and severity of failures. To achieve this objective, two specific strategies will be implemented: preventive maintenance routines and the "Zero Breakdown by Base Condition" methodology. The implementation of preventive maintenance routines consists of establishing a systematic program of inspections, lubrication, adjustments and replacement of components before failures occur. This proactive approach allows you to identify and correct potential equipment problems, preventing them from becoming critical and causing unscheduled interruptions in production. The best maintenance intervals will be studied, taking into account the characteristics and requirements of each equipment, as well as the analysis of data from previous failures. In addition, the "Zero break by base condition" methodology will be implemented. This approach involves continuous monitoring of equipment conditions using data analysis techniques. The objective is to identify abnormal patterns of operation that may indicate the potential for imminent failure. Based on this information, maintenance can be scheduled appropriately and in advance, avoiding unexpected breakdowns. Various monitoring techniques will be explored, such as vibration analysis, thermography and oil analysis, to obtain a comprehensive view of the equipment condition. The study will be carried out in a specific industry, where data will be collected on the availability and reliability of equipment before and after implementing the proposed strategies. Statistical analyzes will be carried out to evaluate the effectiveness of preventive maintenance routines and the "Zero Breakdown by Base Condition" methodology in reducing failures and increasing equipment availability. It is expected that this work will contribute to the development of more efficient and reliable maintenance practices, promoting the improvement of production processes and reducing costs associated with failures and unscheduled stops. Maximizing equipment availability and reliability will have a direct impact on the efficiency and competitiveness of the industry under study.

Keywords: preventive maintenance, zero breakage by base condition, asset management, maintenance costs

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Introduction

Industrial maintenance plays a fundamental role in ensuring the reliable and efficient performance of equipment. The reactive approach, based on failures after they occur, has been replaced by more proactive practices, such as preventive maintenance. Preventative maintenance consists of carrying out inspections, cleaning, lubrication and scheduled adjustments, with the aim of avoiding failures and maximizing the useful life of the equipment. However, traditional preventative maintenance can be improved by adopting the "Zero Breaks by Base Condition" methodology, which uses continuous monitoring and data analysis technologies to identify failures with greater accuracy and take corrective actions sooner than promised. Maintenance is an essential activity to ensure the reliability, availability and useful life of industrial equipment and systems. An effective preventive maintenance approach can prevent ongoing, unscheduled failures, resulting in greater productivity, reduced costs and increased operational safety. The study carried out has the idea of proposing and implementing strategies that aim to maximize the availability and reliability of equipment, reducing the frequency and severity of failures. These strategies will be based on the adoption of preventive maintenance routines, the implementation of a condition monitoring program and the application of data analysis techniques to predict failures.

Main goal

Maximize equipment availability and reliability, reducing the frequency and severity of failures.

Specific objective

a) Implement preventive maintenance routines;

b) Implement the "Zero break by base condition" methodology;

Reference

Maintenance

In industries for several years, equipment maintenance has been used, which consists of maintaining the general good functioning of the machinery. Today in its fourth generation, maintenance has undergone an evolution over the years seeking to improve its methods to obtain better cost and production levels for each period, the main ones being corrective, preventive and predictive maintenance.[1]

Corrective maintenance

Maintenance is carried out after equipment damage or failure, as the name suggests, correcting the problem and putting the machine back into operation. This type of maintenance has emergency characteristics, that is, immediate action. This may result in additional costs due to moving or purchasing parts without prior planning.[1]

Preventive maintenance

Preventative maintenance is a set of actions that aim to prevent equipment and system failures, with the aim of avoiding unscheduled downtime and reducing corrective maintenance costs. It involves carrying out periodic inspections, cleaning, lubrication, adjustments, parts exchanges and functional tests, in accordance with manufacturers' recommendations and applicable technical standards.[2]

Predictive maintenance

Predictive maintenance is based on the analysis of data obtained from the specific equipment that has undergone intervention. In this maintenance, several techniques are adopted to obtain data for analysis such as: Temperature meter, vibration, energy voltage, oil quality, rotation, etc. With these analyzes it is possible to have control over the components, avoiding hasty maintenance and early replacements, thus reducing costs and creating an advantage over other types of maintenance. Planning equipment maintenance activities is necessary to avoid excessive downtime and loss of production with the aim of keeping equipment operating normally without unexpected failures.[3]

What are the benefits of preventive maintenance

Effective maintenance policies can influence the productivity and profitability of a manufacturing system, reduce waste, optimize service times, reduce equipment failures, reduce maintenance costs, increase employee safety, increase the useful life of equipment and components.[4]

This methodology uses well-defined maintenance plans, seeking to improve the availability of machines by reducing downtime due to equipment failure.[5]

In addition to improving productivity, it is also important to create a culture of commitment to the proper handling and use of equipment to increase the useful life of machines and improve the quality of manufactured products. These implementations aim to improve the Mean Time to Repair (MTTR), Mean time between failures (MTBF) and equipment availability.[5]

What impact does preventative maintenance have on the useful life of the equipment?

Preventative maintenance can extend the life of the machine by ensuring that it is kept in good working order and that critical components are replaced or repaired before they fail. This helps to reduce wear and increase the useful life of components, in addition to increasing the reliability of the machine.[6]

Additionally, preventive maintenance can also improve machine performance, ensuring it runs at optimal efficiency. This can help save money in the long run by reducing energy consumption, increasing productivity, and reducing the need for expensive repairs.

On the other hand, the lack of preventive maintenance can lead to increasing problems, such as frequent failures, unscheduled downtime, loss of production and increased repair costs. Furthermore, it can make the machine unsafe for use, increasing the risk of accidents on site.[7]

Preventive maintenance costs in the hydraulic system

In the hydraulic system there are several units that are valves, pumps, hydraulic cylinders, among others, a failure at some point in these components can lead to a possible failure in the system, in the working conditions and at the time of preventive maintenance. Viewing the components and applying preventive correction will have the result entirely linked to the next programming, as the objective is to maximize the machine's performance.[8]

Keeping your hydraulic system up to date is extremely important, as how to have objectives and a cohesive production line to assist in this process, thus ensuring that your equipment works according to the configurations of the manufacturer.[9]

Preventive maintenance is most often seen as a form of expense, but it is essential to improve performance and avoid loss or replacement of equipment. As each system has its own particularities, it is indeed necessary to pay attention to the previous history and plan in a way that best fits.[10]

Methodology

Introduction

In some industries, only the corrective maintenance system is still used, causing greater downtime due to the massive use of machinery. Aiming to reduce downtime/breakdown, it is not interesting for machines to remain idle due to ineffective maintenance problems. To reduce machine downtime and generate greater reliability, this work deals with the implementation of the preventive maintenance routine combined with the "zero breaks per base condition" methodology.

Variables

The variables were divided into some groups according to the method that was applied. Table 1 show the routine models used in preventive maintenance.

When implementing the preventive maintenance routine, some safety systems and conditions for the proper functioning of the accessibility lifting platform were checked and thus they were selected and separated into routines aiming at greater maintenance efficiency.

Depending on the type of equipment/system, preventive maintenance may involve different procedures, parts and time intervals. For example, an accessibility lift requires different preventative maintenance than a refrigeration system.

The frequency of preventive maintenance may vary depending on the type of equipment/system and its importance for business operation.

Some equipment may require daily maintenance, while others may have longer intervals, such as monthly, quarterly or semi-annual. Preventative maintenance involves costs, both in terms of labor, parts and materials.

The purpose of implementing the "zero breakage by base condition" methodology is to establish and maintain the optimal conditions of equipment effectively and at a cost appropriate to business needs, seeking to achieve the "zero breakage" rate, a daily maintenance schedule so that the production employee acts as a guarantor for the preservation of the equipment.

Sample

To carry out the simulation and development of the maintenance routine implementation application, data from a company in the elevator and platform sector focused on accessibility was used as a basis. These data were extracted from the year 2019 until the date of this study, 2023. Excel was used to create tables, and the data system of company "X" in the elevator industry was used to demonstrate the results of applying this methodology.

To carry out the implementation of the "zero breakage by base condition" methodology, the integrity conditions of equipment and process components were evaluated in a robotic cell of a company in the field of manufacturing welded assemblies, defined a base condition and created an action plan, so that the production employee carries out autonomous maintenance, since he is the professional who spends the most time operating the equipment.

Measuring instruments and techniques

In implementing the maintenance routine, data from the company "X" Elevadores was used and after the analysis, measurements of tension, tensioning, durability, continuity and crushing points were used. The post-analysis result was mentioned in Table 1.

Table 1 Verified routines

Routine A	Routine B	Routine C
Checking the port contacts	Column cleaning and inspection	Anti-crush system
Control panel	Automatic redemption test	Well cleaning
Box cleaning	Lubrication	Electrical contact of the Lock (cracked)
Spindle tension	Belt tensioning	Review of spinal fixation

In the "zero breakage by base condition" methodology, data from the failure history of a robotic cell from company "Y" was used to create an action plan based on kaizen (continuous improvement), capable of maintaining the equipment in optimal operating conditions through a list of daily checks carried out by the production employee.

Implementation of the maintenance routine.

Table 2 shows the steps taken in implementing the preventive maintenance routines process.

Table 2 Implementation of the preventive maintenance routines process

No.	Stage	Description
1	Team separation	An engineer responsible for the company, the maintenance manager and two quality supervisors were selected.
2	Choice of equipment	After the team gathered, a study was carried out looking for one that had the most flaws and the equipment chosen was the accessibility lifting platform.
3	Analysis of equipment safety items	At this stage, the main operating and safety items of the equipment were analyzed.
4	Creation of routines	Having gathered all the items from the previous stage, three maintenance routines were created in A, B and C. The aforementioned items were distributed in them.
5	Training for technicians	With the creation of the routines, it was passed on to the technicians who must carry out the routine so that one is done per month following the sequence A, B and C respectively.
6	Application	After completing the training, technicians are able to continue applying maintenance routines.

In the case studied, a lifting platform for accessibility was used to implement preventive maintenance routines. This consists of using the methods following a checklist divided by routine of the equipment's main safety items, bearing in mind that the equipment will not work if a security breach occurs.

Implementation of the methodology: "Zero break by base condition"

Table 3 shows the steps taken in implementing the process. An action plan was developed in which information about the tasks to be carried out for the robotic cell of company "Y" is recorded.

Table 3 Implementation of the "zero break by base condition" methodology

No.	Phases	Description
1	Project Opening Term	Presentation of the project to company Management.
2	Team selection	Formation of a team of professionals from different sectors of the company, enabling the use of different techniques to solve different problems.
3	Choice of equipment	A study was carried out using the history of failures, and the Y robotic cell was chosen to implement the methodology.
4	Identification of opportunities and improvements	Meeting of the multifunctional team to detect procedural flaws and analyze all problems that need to be resolved.
5	Goals and objectives	Achieve "zero breakage by base condition".
6	Construction of the action plan	Definition of what will be done, when it will be done, by whom it will be done, where it will be done, how much it will cost, what budget is available, etc.
7	Execution of activities	According to the action plan, everyone must perform their part, helping others when necessary and respecting the defined budget and deadlines.
8	Monitoring and evaluating results	Monitoring the evolution of actions and, if necessary, making the necessary adjustments.

Table 3 presents the steps taken during the implementation of the "zero break by base condition" methodology. An action plan was prepared that records information about the tasks to be carried out for the robotic cell of company "Y". The selection of the team allowed the use of different techniques to solve the identified problems. The study carried out resulted in the choice of the Y robotic cell as the target equipment for implementing the methodology. The team identified opportunities for improvement, defined objectives and goals, and built a detailed action plan that included deadlines, responsibilities and budget.

Project breakdown structure (WBS)

In Figure 1, it is possible to visualize in more detail the stages of implementing the "zero break by base conditions" methodology.

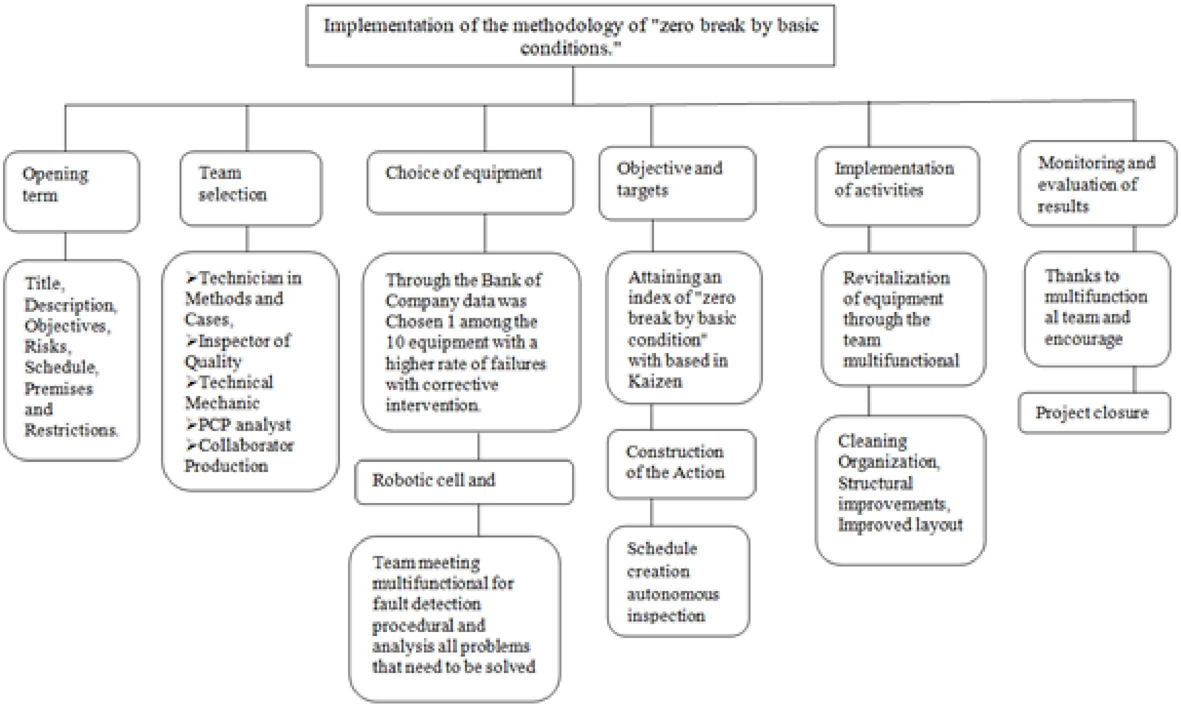

Figure 1 Project Analytical Structure (EAP).

It is a structure that organized the project to implement the "zero break by base condition" methodology, enabled an overview, facilitating better decision-making by the project manager, showed the main phases of the project, mapped the tasks necessary to achieve the expected result.

PLIA –Y robotic cell cleaning and inspection plan

Table 4 shows the production employee's new inspection document, enabling them to act in relation to the preservation and conservation of the equipment.

Table 4 PLIA - Cleaning and Inspection Plan for Robotic Cell Y

May 2023					
PLIA Activities - Cleaning and Autonomous Inspection Plan for Robotic Cell Y					
	Week 1				
Cleaning Activities	Second	Third	Fourth	Fifth	Friday
Clean inductive sensors to ensure their operation					
Keep device clean and organized					
Maintain cleanliness and organization of the Cell					
Clean the robot's gripper by eliminating solder sludge and dust					
Inspection Activities					
Tooling: Inspect wear, play or lack of alignment					
Check whether the hydraulic and pneumatic valves are activated					
Pressure gauge: Inspect the working range of 4 to 6 Bar					
Technological Pins: Inspect wear and fixation to ensure geometry					
Subtitles: C= Conform NC= Non Conform					

This document shows the items to be inspected by the production employee. If the production employee finds any NC (Non-Conformity) during the inspection, he will open a preventive maintenance order, letting the Maintenance sector know to plan the intervention.

Working hypothesis

Joint implementations of established practices can result in significant improvements in the company's performance indicators, such as:

1) Reduction of unscheduled downtime;
2) Reducing maintenance costs, optimizing the use of resources, increasing productivity and extending the useful life of equipment.

Results

Upon completing the application of the methodology, it becomes evident in several stages where analyzes were conducted to obtain the results of the implementation of preventive maintenance routines and the "Zero Breakdown by Base Condition" approach.

Implementation of the maintenance routine

In this first part, a case of an accessibility lifting platform was analyzed before the use of preventive maintenance routines, as shown in Figure 1. According to the data obtained from company "X" elevators, it is worth highlighting that it did not use the routine preventive maintenance method. , just called correctives.

In Figure 2, the data shows the number of corrective calls answered over a 12-month period on an accessibility lifting platform. Around 17 calls answered, on average 1.41 calls per month in 2019.

	Ticket	Term	Technician	Entry date	Exit date	Time	Client
✓	006674/244	13/01/2019	XX-Outro Tecnico	12/01/2022	12/01/2022	Normal	(9001) UNIASSELVI I;
✓	006674/245	07/03/2019	XX-Outro Tecnico	06/03/2022	06/03/2022	Normal	(9001) UNIASSELVI I;
✓	006674/258	21/03/2019	XX-Outro Tecnico	20/03/2022	20/03/2022	Normal	(9001) UNIASSELVI I;
✓	006674/259	22/03/2019	XX-Outro Tecnico	21/03/2022	21/03/2022	Normal	(9001) UNIASSELVI I;
✓	006674/260	03/04/2019	XX-Outro Tecnico	02/04/2022	02/04/2022	Normal	(9001) UNIASSELVI I,
✓	006674/262	02/05/2019	XX-Outro Tecnico	01/05/2022	01/05/2022	Normal	(9001) UNIASSELVI I,
✗	006674/263	27/05/2019	XX-Outro Tecnico			Normal	(9001) UNIASSELVI I
✓	006674/264	27/06/2019	XX-Outro Tecnico	26/06/2022	26/06/2022	Normal	(9001) UNIASSELVI I
✓	006674/266	15/09/2019	XX-Outro Tecnico	14/09/2022	14/09/2022	Normal	(9001) UNIASSELVI I
✓	006674/268	22/09/2019	XX-Outro Tecnico	22/09/2022	22/09/2022	Normal	(9001) UNIASSELVI I
✓	006674/269	26/09/2019	XX-Outro Tecnico	25/09/2022	25/09/2022	Normal	(9001) UNIASSELVI I,
✓	006674/270	11/10/2019	XX-Outro Tecnico	10/10/2022	10/10/2022	Normal	(9001) UNIASSELVI I,
✓	006674/273	24/10/2019	XX-Outro Tecnico	23/10/2022	23/10/2022	Normal	(9001) UNIASSELVI I,
✓	006674/274	31/10/2019	XX-Outro Tecnico	28/10/2022	28/10/2022	Normal	(9001) UNIASSELVI I,
✓	006674/275	02/11/2019	XX-Outro Tecnico	01/11/2022	01/11/2022	Normal	(9001) UNIASSELVI I
✓	006674/276	03/11/2019	XX-Outro Tecnico	02/11/2022	02/11/2022	Normal	(9001) UNIASSELVI I
✓	006674/277	21/11/2019	XX-Outro Tecnico	20/11/2022	20/11/2022	Normal	(9001) UNIASSELVI I
✓	006674/279	12/12/2019	XX-Outro Tecnico	11/12/2022	11/12/2022	Normal	(9001) UNIASSELVI I

Figure 2 Corrective calls before using maintenance routines.

The so-called correctives most often generate repairs, which are relatively parts exchanges and which were sold to the customer according to the pending issue generated. As we see in Figure 3.

This happens because so-called correctives are requested when the equipment stops working. In most cases due to broken parts or misadjustment of systems essential for the operation of the lifting platform. In this case, there were 9 repairs in a 12-month period in 2019.

After these analyzes in 2019, the company "X" Elevadores adopted the routine preventive maintenance method carried out monthly as mentioned in Table 1.

	Ticket	Issuance/ termination	Conclusion	Client
✓	006674/159	07/01/2019 01/02/2019	30/01/2019	(9001) UNIASSELVI I
✓	006674/164	07/02/2019 21/02/2019	19/02/2019	(9001) UNIASSELVI I
✓	006674/165	07/02/2019 31/05/2019	30/05/2019	(9001) UNIASSELVI I
✓	006674/169	27/02/2019 31/05/2019	29/05/2019	(9001) UNIASSELVI I
✓	006674/175	12/03/2019 31/05/2019	30/05/2019	(9001) UNIASSELVI I
✓	006674/188	17/06/2019 02/07/2019	27/06/2019	(9001) UNIASSELVI I
✓	006674/194	30/07/2019 16/08/2019	09/08/2019	(9001) UNIASSELVI I
✓	006674/197	02/10/2019 23/10/2019	11/10/2019	(9001) UNIASSELVI I
✓	006674/198	17/10/2019 01/11/2019	18/10/2019	(9001) UNIASSELVI I

Figure 3 Repairs carried out before routine preventive maintenance was used.

In Figure 4 it is possible to see some details that show the application of the preventive maintenance routine system.

In Figure 4 it is seen that 12 preventive services were carried out following routines A, B and C (Table 1) respectively during the 12-month period. With it, you can see details of the technician's arrival and departure days on site and the frequency of understanding in addition to the customer served.

	Ticket	Term	Frequency	Technician	Entry date	Entry date	Time	Routine	Client
✓	072007/070	31/01/2020	Mensal	XX-Outro Tecnico	27/01/2020	27/01/2020	Normal	A	(9001) UNIASSELVI I
✓	072007/071	29/02/2020	Mensal	XX-Outro Tecnico	26/02/2020	26/02/2020	Normal	B	(9001) UNIASSELVI I
✓	072007/072	31/03/2020	Mensal	XX-Outro Tecnico	25/03/2020	25/03/2020	Normal	C	(9001) UNIASSELVI I
✓	072007/073	30/04/2020	Mensal	XX-Outro Tecnico	27/04/2020	27/04/2020	Normal	A	(9001) UNIASSELVI I
✓	072007/074	31/05/2020	Mensal	XX-Outro Tecnico	19/05/2020	19/05/2020	Normal	B	(9001) UNIASSELVI I
✓	072007/075	30/06/2020	Mensal	XX-Outro Tecnico	17/06/2020	17/06/2020	Normal	C	(9001) UNIASSELVI I
✓	072007/076	31/07/2020	Mensal	XX-Outro Tecnico	15/07/2020	15/07/2020	Normal	A	(9001) UNIASSELVI I
✓	072007/085	31/08/2020	Mensal	XX-Outro Tecnico	12/08/2020	12/08/2020	Normal	B	(9001) UNIASSELVI I
✓	072007/086	30/09/2020	Mensal	XX-Outro Tecnico	08/09/2020	08/09/2020	Normal	C	(9001) UNIASSELVI I
✓	072007/087	31/10/2020	Mensal	XX-Outro Tecnico	07/10/2020	08/10/2020	Normal	A	(9001) UNIASSELVI I
✓	072007/088	30/11/2020	Mensal	XX-Outro Tecnico	03/11/2020	05/11/2020	Normal	B	(9001) UNIASSELVI I
✓	072007/089	31/12/2020	Mensal	XX-Outro Tecnico	10/12/2020	10/12/2020	Normal	C	(9001) UNIASSELVI I

Figure 4 Preventive maintenance by routines carried out.

After implementation, the result of the same equipment was monitored after 12 months in the following year (2020).[11] As shown in Figure 5, a drop in the number of corrective calls is seen.

	Ticket	Term	Technician	Entry date	Exit date	Time	Client
✓	006674/218	18/09/2020	XX-Outro Tecnico	18/09/2020	18/09/2020	Normal	(9001) UNIASSELVI I
✓	006674/219	24/09/2020	XX-Outro Tecnico	24/09/2020	24/09/2020	Normal	(9001) UNIASSELVI I
✓	006674/220	10/11/2020	XX-Outro Tecnico	10/11/2020	10/11/2020	Normal	(9001) UNIASSELVI I

Figure 5 Corrective calls after using preventive maintenance routines.

As seen, preventive maintenance has an advantage over corrective maintenance. This is due to inspections and adjustments of the main systems and parts of the equipment (accessibility lifting platform) before they become damaged or out of adjustment, causing the equipment to stop. It can be seen in Figure 5 that 3 corrective calls were made, 14 fewer compared to the same equipment in 2019.

However, in Figure 6, it can also be seen that there is a drop in the number of repairs carried out.

	Ticket	Issuance/ termination	Conclusion	Client
✓	007856/187	14/02/2020 21/02/2020	20/02/2020	(9001) UNIASSELVI I
✓	007856/188	09/03/2020 25/06/2020	31/03/2020	(9001) UNIASSELVI I
✓	007856/189	18/03/2020 25/06/2020	31/03/2020	(9001) UNIASSELVI I
✓	007856/202	19/08/2020 01/12/2020	24/11/2020	(9001) UNIASSELVI I

Figure 6 Repairs carried out after implementing routine preventive maintenance.

Due to the check-ups carried out during preventive maintenance routines, the useful life of the parts is prolonged, thus generating fewer pending parts and therefore needing to be replaced. There were 4 repairs carried out in 12 months in 2020,[11] 5 repairs less than 2019 on the same equipment, as can be seen in Figure 6.

It is worth remembering that even though there was a drop in repairs, some were carried out throughout the year. Because even with frequent checks and adjustments, the parts have a useful life. Even if prolonged, they are not eternal and require replacement over time, because each one has a lifespan and follows the manufacturer's instructions.

Results of the implementation of the "zero break by base condition" methodology

Table 5 shows the failure history of robotic cell Y, in the period from January to April 2023. The implementation of the "zero breakage by base condition" methodology was carried out in March 2023.

Table 5 History of Y robotic cell failures in the period from January to April 2023

Note	Description	Order	Date	Installation location	Equipment	Stopped duration	User status	Hinic Av
200997080	Failed cell gateway	71000505	10.01.2023	Y Robotic Cell	140008C001	0.80	PESU	14:00
200997258	Activation failure	70999350	11.01.2023	Y Robotic Cell	140008C001	0.50	PESU	10:30
200999945	Cylinder failure	71002080	01/23/2023	Y Robotic Cell	140008C001	0.24	PESU	17:45
201000764	Maintenance	71002798	01/26/2023	Y Robotic Cell	140008C001	0.64	PESU	15:21
201001915	Failed device	71003970	01/31/2023	Y Robotic Cell	140008C001	0.50	PESU	8 o'clock
201003471	Cylinder failure	71005532	06.02.2023	Y Robotic Cell	140008C001	1.01	PESU	12:42
201006308	Maintenance	71007384	02/08/2023	Y Robotic Cell	140008C001	0.38	PESU	10:07
201006560	Failed SX line	71007742	09.02.2023	Y Robotic Cell	140008C001	0.48	PESU	10:41
201007583	Weld bead adjustments	71009145	02/13/2023	Y Robotic Cell	140008C001	1.73	PESU	09:00
201009666	More adjustments/adjustments...	71011127	23.02.2023	Y Robotic Cell	140008C001	0.30	PESU	07:09
201010271	Op sensor failure. 05.	71011714	24.02.2023	Y Robotic Cell	140008C001	0.50	PESU	09:30
201016204	Absence of part	71016806	10.03.2023	Y Robotic Cell	140008C001	0.21	PESU	13:22
201016621	Failure to assemble the	71017320	03/13/2023	Y Robotic Cell	140008C001	0.33	PESU	14:10
201016847	Robot does not deposit part	71017492	03/14/2023	Y Robotic Cell	140008C001	0.44	PESU	13:03
201017316	Maintenance	71017769	03/16/2023	Y Robotic Cell	140008C001	0.30	PESU	07:12
201019845	Maintenance	71020369	03/24/2023	Y Robotic Cell	140008C001	0.40	PESU	14:00
201024018	Maintenance	71024653	04/12/2023	Y Robotic Cell	140008C001	0.16	PESU	08:28
201024263	Maintenance	71024838	04/13/2023	Y Robotic Cell	140008C001	0.23	PESU	07:14
201025011	Leaking water	71026074	04/15/2023	Y Robotic Cell	140008C001	0.45	PESU	09:00
201025015	Align electrode holder	71026073		Y Robotic Cell	140008C001	0.25	PESU	11:00

During the analysis period, there were 5 interventions in the month of January, generating 160.8 minutes of unscheduled stops in the month due to equipment breakdown, in February there were 6 interventions generating 264 minutes of stops, in March there were 5 interventions generating 100.8 minutes of stops and in April there were 4 interventions generating 65.4 minutes of unscheduled stops due to equipment breakdown, as can be seen in Table 5.

With the implementation of the "zero breakage by base condition" methodology, the equipment broke down less in March and April, making it more available for production.

Table 6 shows the MTBF and MTTR of robotic cell Y. It can be observed the increase in MTBF and the reduction in MTTR in March and April with the implementation of the "zero break by base condition" methodology, in relation to January and February 2023 without implementation.

Table 6, shows the first pillar, the months of analysis of 2023, the second pillar, shows the total time scheduled for each month to produce on the equipment in hours, the third pillar, shows the total downtime for each month in hours, the fourth pillar, shows the total number of stops in each month, the fifth pillar, shows the MTBF for each month and the sixth pillar, shows the MTTR for each month.

Table 6 Analysis of MTBF and MTTR of robotic cell Y in the period from January to April 2023

Year 2023	Scheduled time	Total stop time	Number of stops	MTBF	MTTR
January	333.46	2.68	5	66.16	0.54
February	280.86	4.40	6	46.08	0.73
March	346.61	1.68	5	68.99	0.34
April	291.90	1.09	4	72.70	0.27

MTBF is an indicator that analyzes the average time between failures, that is, the longer the average time between one failure and another, the better. The MTBF is determined by Equation 1.

$$MTTR = \frac{Total\ repair\ time}{Number\ of\ stops} \quad (1)$$

Where:

- MTBF = mean time between failures;
- Scheduled time = Time in hours;
- Total stop time = Time in hours;
- Number of stops = Number of stops.

MTTR is an indicator that analyzes the average repair time, it divides the total downtime by the number of failures, the shorter the average repair time, the better. The MTTR is determined by Equation 2.

$$MTTR = \frac{Total\ repair\ time}{Number\ of\ stops} \quad (2)$$

Where:

- MTTR = Average Repair Time
- Total repair time = Time in hours;
- Number of stops = Number of stops.

Table 7 shows the Availability of robotic cell Y in the analysis period.

Table 7 Availability Analysis of robotic cell Y in the period from January to April 2023

Scheduled time	Total stop time	Availability
333.46	2.68	99.20%
280.86	4.40	98.43%
346.61	1.68	99.52%
291.90	1.09	99.63%

The Y robotic cell presented 99.20% availability in January, in February the cell's availability reduced to 98.43% and with the implementation of the "zero breakdown due to base conditions" methodology the availability indicator rose to 99.52% in March and 99.63% in April.

The last step is to calculate availability, which is the indicator that analyzes the percentage of time that the equipment was available for production. Availability is determined by Equation 3.

$$Availability = \frac{Charging\ time - Total\ stopping\ time}{Charging\ time} \quad (3)$$

Where:

- Charging time= Time in hours;
- Total stop time = Time in hours.

The objective of implementing the "zero break by base condition" methodology was successfully achieved, as the company's goal was to achieve an index of 68 hours/month in the MTBF indicator, reaching 0.5 hours/month in the indicator of MTTR and reach 99.5% in the equipment availability indicator.

Conclusions

It was demonstrated throughout the work that the implementation of preventive maintenance routines and the "Zero Breakdown by Base Condition" methodology is an effective strategy to improve asset management and increase the availability of industrial equipment, as the number of of unscheduled downtime of machines as the change from corrective to preventive maintenance.

These practices allowed the proactive identification of problems and the carrying out of precise interventions, avoiding unexpected failures and reducing maintenance costs. The author Serra, Danilo da Silva et al. (2022)[2] mentions preventive maintenance and raised in the objective generates which aims to maximize, availability and reliability of equipment, reducing the frequency and severity of failures, which corroborates this work.

The methodologies implemented offered an advanced approach to monitoring and data analysis, contributing to a continuous cycle of improvement in industrial maintenance such as: reducing unscheduled downtime, reducing maintenance costs, optimizing the use of resources, increasing productivity and prolongation of the useful life of equipment resulting in the purpose of specific work objectives. It is expected that the implementation of preventive maintenance routines and the "Zero Breakdown by Base Condition" methodology will significantly contribute to maximizing equipment availability and reliability, reducing the frequency and severity of failures. This will bring economic and operational benefits to the industry, such as reduced repair costs, increased productivity and improved customer satisfaction.

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Conflicts of interest

The authors declare that there are no conflicts of interest.

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