STRUCTURING A PREVENTIVE MAINTENANCE PLAN WITH A FOCUS ON OPERATIONAL RELIABILITY: A CASE STUDY IN THE METALLURGICAL SECTOR

ESTRUTURAÇÃO DE UM PLANO DE MANUTENÇÃO PREVENTIVA COM FOCO NA CONFIABILIDADE OPERACIONAL: UM ESTUDO DE CASO NO SETOR METALÚRGICO

ESTRUCTURACIÓN DE UN PLAN DE MANTENIMIENTO PREVENTIVO CON ENFOQUE EN LA CONFIABILIDAD OPERACIONAL: UN ESTUDIO DE CASO EN EL SECTOR METALÚRGICO

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ABSTRACT

Maintenance and reliability systems are relevant in all business sectors, as effective maintenance contributes to efficient operational performance, reducing risks and costs. The objective of this study was to identify quality tools applicable to maintenance planning and to support the proposition of a plan aimed at restructuring and optimizing existing processes. This descriptive research adopted an approach based on a biblioFigureic review, followed by its application in a case study conducted in a medium-sized company in the iron and steel sector, with 15 years of experience in the market. The company provides a wide range of products and services, including longitudinal and transverse cutting, flat steel, galvanized steel, and heavy plates, complying with strict industrial standards and maintaining a high level of quality. The results showed that the application of quality tools, such as the Pareto Diagram and the Ishikawa Diagram, is essential for identifying critical failure points and for developing a prototype preventive maintenance plan. Although the complete development of the plan was not possible within the scope of this study, the proposed prototype provides a solid basis for the future implementation of preventive actions, directing efforts toward the most critical components of the Slitter and allowing replication in other equipment and systems of the company.

Keywords: FMEA. Ishikawa. Pareto. Maintenance. Metalworking Industry.

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RESUMO
Os sistemas de Manutenção e Confiabilidade são relevantes em qualquer setor empresarial, pois uma manutenção eficaz contribui para uma execução eficiente na operação, com redução de riscos e custos. O objetivo deste estudo foi de levantar possíveis ferramentas de qualidade aplicáveis ao planejamento de manutenção e fundamentar a proposição de um plano que reestruture e otimize os processos existentes. Para o desenvolvimento deste trabalho, de natureza descritiva, adotou-se uma abordagem baseada em um levantamento bibliográfico, sucedido pela aplicação em um estudo de caso, desenvolvido em uma indústria de médio porte do setor de ferro e aço, com 15 anos de atuação no mercado, que fornece uma variedade de produtos e serviços, incluindo cortes longitudinais e transversais, aços planos, galvanizados e chapas grossas, cumprindo rigorosas normas industriais e mantendo um alto padrão de qualidade. Como resultado, as análises realizadas evidenciaram que a aplicação de ferramentas da qualidade, como o Diagrama de Pareto e o Diagrama de Ishikawa, é fundamental para a identificação dos pontos críticos de falhas e para a construção do protótipo do plano de manutenção preventiva. Embora o desenvolvimento completo do plano não tenha sido possível dentro do escopo deste estudo, o protótipo apresentado oferece uma base sólida para a implementação futura de ações preventivas, direcionando os esforços para os componentes mais críticos da Slitter, podendo ser replicados nos demais equipamentos e sistemas da empresa.

Palavras-chave: FMEA. Ishikawa. Pareto. Manutenção e Indústria Metalúrgica.

RESUMEN
Los sistemas de Mantenimiento y Confiabilidad son relevantes en cualquier sector empresarial, ya que un mantenimiento eficaz contribuye a una ejecución operativa eficiente, con la reducción de riesgos y costos. El objetivo de este estudio fue identificar posibles herramientas de calidad aplicables a la planificación del mantenimiento y fundamentar la propuesta de un plan orientado a reestructurar y optimizar los procesos existentes. Para el desarrollo de este estudio de carácter descriptivo, se adoptó un enfoque basado en una revisión bibliográfica, seguida de su aplicación en un estudio de caso realizado en una industria de tamaño medio del sector del hierro y el acero, con 15 años de actuación en el mercado. La empresa ofrece una amplia variedad de productos y servicios, incluyendo cortes longitudinales y transversales, aceros planos, galvanizados y chapas gruesas, cumpliendo estrictas normas industriales y manteniendo un alto estándar de calidad. Como resultado, los análisis evidenciaron que la aplicación de herramientas de calidad, como el Diagrama de Pareto y el Diagrama de Ishikawa, es fundamental para la identificación de los puntos críticos de falla y para la construcción del prototipo del plan de mantenimiento preventivo. Aunque el desarrollo completo del plan no fue posible dentro del alcance de este estudio, el prototipo presentado ofrece una base sólida para la futura implementación de acciones preventivas, orientando los esfuerzos hacia los componentes más críticos de la máquina slitter, pudiendo ser replicado en los demás equipos y sistemas de la empresa.

Palabras clave: FMEA. Ishikawa. Pareto. Mantenimiento e Industria Metalúrgica.

1 INTRODUCTION

In today's industrial landscape, marked by a highly competitive environment and continuous technological advancements, companies are constantly seeking to improve their operations to achieve greater efficiency and reduce operating costs. Globalization and the pressure for high quality products, offered at competitive prices, require industries to manage their resources and processes more strategically (KARDEC, 2004). In this context, the reliability of equipment plays a crucial role, as failures or unexpected downtime can result in high costs, compromising the production flow and the quality of products. Maintenance practices, traditionally seen as reactive activities, have been evolving into preventive and predictive approaches, focused on ensuring the availability and longevity of industrial assets (SANTOS et al., 2019).

Maintenance planning emerges, therefore, as a key piece for industries to reduce equipment downtime, optimize the use of resources, and maximize productivity. According to SANTOS et al. (2019), a well-structured approach to maintenance can significantly reduce operating costs and minimize the impact of unscheduled failures. An effective preventive maintenance plan is essential to protect machinery investments, decrease unexpected downtime and emergency costs, and consequently increase productivity. However, many companies still face challenges in implementing these practices due to disorganized processes and poor communication between maintenance and operation teams. Efficient maintenance management is essential to achieve continuous improvement and maintain competitiveness in today's industrial environment (SANTOS et al., 2019).

In this context, the present study aims to investigate quality tools that can support the creation of a more assertive preventive maintenance plan. For the development of this descriptive work, a methodology was adopted that combines biblioFigureic survey and practical application in a case study. The study was carried out in a medium-sized industry in the iron and steel sector, with 15 years in the market, which stands out for offering a range of products and services, such as longitudinal and transverse cuts, flat steel, galvanized steel, and heavy plates. This company adheres to strict industry standards while maintaining a high level of quality in its processes and products. Although the company has well-established maintenance procedures, such as work orders and performance indicators, the current process still has important gaps, particularly in aspects related to the organization and communication of preventive activities. Given the importance of equipment for the production line and the significant impact of any failures, the structuring of a more detailed preventive maintenance plan focused on critical points of improvement emerges as a necessity.

In summary, this case study aims to develop a prototype of a preventive maintenance plan for Slitter, a rotary shear used in the cutting and processing of materials in coils, based on a careful analysis of historical corrective maintenance data and the application of quality tools. The work uses the Six Sigma methodology as a structural basis and adopts the DMAIC process – Define, Measure, Analyze, Improve and Control – for the development of the steps and analyses. DMAIC is a data-based quality methodology, widely used in continuous improvement projects for problem solving and process optimization. An integral part of Six Sigma, this approach can be applied autonomously in quality improvement initiatives or integrated with other strategies, such as Lean, offering systematic ways to develop more robust and controlled processes (AMERICAN SOCIETY FOR QUALITY, 2024).

To enable the implementation of a future preventive maintenance plan, quality tools such as the Pareto Chart and the Ishikawa Chart can be used, which provide a reasoned analysis of the most recurrent failures and their possible causes. In addition, an Excel spreadsheet was prepared for the construction of the FMEA, Failure *Modes and Effects Analysis*, with the objective of assisting the company in the systematic analysis of the modes and effects of failures, promoting a more accurate and grounded approach. Although the practical application of FMEA has not been fully implemented within the scope of this work, its structuring represents an important step towards providing the company with an instrument that favors the continuity and expansion of preventive maintenance practices.

The present work is organized as follows: section 2 addresses the theoretical foundation and the quality tools applied; Section 3 presents the methodology used for the analysis and development of the maintenance plan; Section 4 exposes the results and discussions of the analyses; and, finally, section 5 brings the final considerations and recommendations for future work.

2 THEORETICAL FRAMEWORK

2.1 TYPES OF MAINTENANCE

The Industrial Maintenance of a company goes beyond the choice of intervention strategies in the equipment, encompassing organizational tools, planning techniques, professional qualification, quality indicators and a management system. The selection of maintenance strategies considers the manufacturer's recommendations, safety, environmental impact, equipment characteristics and economic viability, forming a solid basis for an effective maintenance policy (VIANA, 2002).

According to TEIXEIRA (2022), maintenance has undergone a continuous process of improvement, evolving in its approaches. At the beginning of the last century, still present in some organizations, maintenance was predominantly corrective. However, as the years progressed, more proactive strategies emerged, giving way to preventive maintenance, and later, reaching more refined levels in the form of predictive maintenance. Industrial maintenance aims to ensure the functional availability of equipment and facilities, keeping the production process safe, reliable and within costs.

According to MOSCHIN (2015), the scheduled shutdown for maintenance of a process unit aims to restore and/or improve the conditions of equipment and facilities. The author states that, after a certain period of operations, production capacity is lost and product degradation and production losses may occur, compromising the safety of facilities and equipment reliability, resulting in the need for reconditioning. The shutdown is an especially important event in continuous processing plants, which operate 24 hours a day, seven days a week. Therefore, the importance of understanding the applications of the types of analysis and how the types of maintenance are divided into different sectors of the industry.

Within the scope of this study, different types of maintenance were considered. According to VIANA (2002), the types of maintenance refer to the various approaches to carrying out interventions in the equipment that makes up a production plant. Considering this definition, there is a consensus, with minimal variations, on the types of maintenance. For the author, the main types are:

2.2 CORRECTIVE MAINTENANCE

The Brazilian Association of Technical Standards ABNT (NBR 5462 – 1994) defines corrective maintenance as maintenance performed after the occurrence of a breakdown, aimed at putting an item back in a condition to perform a required function. In this case, the correction is carried out only after the equipment has broken down.

According to SANTOS (2018), corrective maintenance is a maintenance activity carried out to overcome failures or damages found during the preventive maintenance period. In general, this is not a scheduled maintenance activity, because it is done after a component is damaged and aims to restore the reliability of a component or system to its original state.

According to VIANA (2002), corrective maintenance can be divided into:

- Unplanned Corrective Maintenance: This maintenance occurs after the failure or loss of performance of a piece of equipment, with no prior time to prepare the services. Despite the inconvenience caused, this form of maintenance is still widely used today.
- Planned Corrective Maintenance: Refers to the correction of a lower than expected performance or a failure, by managerial decision. This can occur both through

predictive tracking and the decision to continue operating the equipment until a breakdown occurs.

2.3 PREVENTIVE MAINTENANCE

Preventive maintenance, defined by the ABNT standard (NBR 5462 – 1994), is carried out at predetermined intervals, or according to prescribed criteria, aimed at reducing the probability of failure or degradation of the operation of an item. This modality aims to eliminate or reduce the probability of failures through activities such as cleaning, lubrication, replacement, and checking at pre-planned intervals. For this reason, it is necessary that time intervals are properly defined in order to achieve efficient preventive maintenance (SLACK; CHAMBERS; JOHNSTON, 2009).

The definition of maintenance intervals must consider variables such as the criticality of the equipment and the history of failures. This approach, although initially costly, reduces the number of unexpected stops and increases production efficiency over time (VILLANUEVA, 2015).

2.4 PREDICTIVE MAINTENANCE

Predictive maintenance, according to the ABNT standard (NBR 5462-1994), consists of systematic analysis techniques that aim to ensure a desired quality of service. Using centralized supervision or sampling means to reduce preventive and corrective maintenance to the minimum necessary.

According to VIANA (2002), predictive maintenance is a type of preventive maintenance that is based on the actual condition of the equipment. This method allows continuous monitoring of the equipment through measurements taken during its normal operation, which provides greater availability, as the intervention occurs only when it approaches a limit previously established by the maintenance team. Predictive maintenance, therefore, predicts equipment failure, and repair intervention is actually configured as scheduled corrective maintenance.

The essential conditions for the implementation of this type of maintenance are: a) The equipment, system or installation must allow some type of monitoring; b) The choice for this type of maintenance must be justified by the costs involved; c) Failures must originate from causes that can be monitored and have their progression monitored (VIANA, 2002).

2.5 MAINTENANCE INDICATORS

Maintenance indicators can measure different aspects of performance, from downtime to the efficiency of the production process. As a future work, it is suggested that some of these indicators be used for daily monitoring and control of maintenance and as confirmation of the feasibility of the maintenance plan that will be built. It is worth mentioning that indicators are not only used to monitor maintenance challenges, but are also essential for the daily routine.

Maintenance ratios should reflect crucial aspects of the production process. For some companies, a certain indicator may be satisfactory, while for others, it may not be so applicable, being a matter of analysis and adaptation. Maintenance Planning and Control (PCM) must evaluate the best way to monitor its process (VIANA, 2002).

2.6 MEAN TIME BETWEEN FAILURES *(MTBF)*

According to VIANA (2002, p. 142), the mean time between failures "is defined as the division of the sum of the hours available of the equipment for operation (HD), by the number of corrective interventions in this equipment in the period (NC)".

The MTBF index is used to monitor the performance of machines in response to maintenance activities. An increase in the value of this indicator over time is a positive sign, as it suggests a reduction in corrective interventions and, therefore, an increase in available operating hours (VIANA, 2002).

Equation 1 presents the calculation used.

$$MTBF = \frac{HD}{NC} \quad (1)$$

2.7 MEAN TIME TO REPAIR *(MTTR)*

Mean time to repair (MTTR) is calculated by dividing the sum of hours of operational downtime due to maintenance (HIM) by the number of corrective interventions performed in the period (NC). It can be inferred that the lower the MTTR over time, the more effective maintenance management will be, since corrective interventions will have an increasingly smaller impact on production (VIANA, 2002).

Equation 2 represents the calculation of this maintenance indicator.

$$MTTR = \frac{HIM}{NC} \quad (2$$

2.8 PHYSICAL AVAILABILITY (DF)

According to ABNT (NBR 5462 – 1994), availability is defined as the ability of an item to be in a position to perform a certain function at a given time or during a specific time interval. The formula for calculating availability can vary between different production sectors and even between competing companies.

In general, physical availability (FD) is defined as the percentage of the ratio between the total accumulated operating hours (HO) and the total elapsed hours. HO refers to the total time of operation, while HM corresponds to the time of stoppages, both preventive and corrective. Losses due to underspeed do not affect physical availability, but only impact productivity (VIANA, 2002).

This index is extremely important for maintenance, as the main objective is to maximize DF, that is, to provide the largest possible number of hours of equipment operation. In addition, the index should be used to monitor the operational performance of the equipment, identifying 'problem equipment', those that most negatively impact the plant's FD (VIANA, 2002).

Equation 3 represents the calculation of FD.

$$DF = \frac{HO}{HO + HM}\, x\, 100\% \qquad (3)$$

2.9 SIX SIGMA

According to WERKEMA (2006), Six Sigma is a management strategy characterized by its disciplined and analytical approach. This method aims to improve organizational performance and promote significant improvements in quality and customer satisfaction. As noted by the author, this strategy aims at the continuous optimization of processes and products, resulting in greater competitiveness and profitability for the organization.

MITCHELL (1992) describes Six Sigma as a Statistical Process Control approach, designed to achieve levels of excellence with only 3.4 defects per million opportunities in various areas, such as manufacturing, services and product development. This method is based on the principles of Total Quality Management and is differentiated by the intensive application of quantitative tools to identify and eliminate unwanted variabilities.

The Six Sigma structure is organized around the DMAIC cycle – Define, Measure, Analyze, Improve and Control – which guides the progress of improvements in each phase of the project (REVELLE, 2004). According to WERKEMA (2006), the stages of the cycle are briefly defined as follows:

- Define: define the scope of the project;
- Measure: determine the focus of the problem;
- Analyze: determine the causes of the priority problem;
- Improve: propose, evaluate and implement solutions to the priority problem;
- Control: ensure that the achievement of the goal is maintained in the long term.

According to ARNHEITER & MALEYEFF (2005), by applying the Six Sigma method and its principles, the organization can enjoy a series of benefits, including continuous improvement of processes, improvement of quality, optimization of workflow, increase in efficiency and productivity, reduction of cycle times, expansion of production capacity and reliability of products, reduction of defects, waste and costs, elimination of activities that do not add value and maximization of profits.

2.10 FAILURE MODES AND EFFECTS ANALYSIS (FMEA)

Failure Mode and Effects Analysis *(FMEA)* is a technique that aims to ensure the reliability of processes and products, with three main objectives: (i) to identify and evaluate possible failures that may occur in a product or process, (ii) to determine preventive or corrective actions to minimize the probability of these failures occurring, and (iii) document the study in order to create a technical reference that serves as a basis for future revisions and improvements in the process or project (FOGLIATTO and RIBEIRO, 2009).

Process FMEA, in particular, is an analytical approach applied by the process development team to ensure that potential failure modes, their causes and effects, are properly identified and discussed. In this FMEA modality, all steps, procedures, and process operations are thoroughly examined to identify possible failure modes that may compromise product quality. This study serves as a structured record of the team's discussions, based on the practical experience and accumulated knowledge of the professionals involved (FOGLIATTO and RIBEIRO, 2009).

Process FMEA can be used in both industrial and administrative settings, offering a systematic methodology that formalizes and documents team considerations throughout the planning and continuous process improvement stages. This technique contributes to the reduction of risks, allowing a more careful evaluation of the process requirements and ensuring that all potential modes of failure and their associated causes and effects are analyzed (FOGLIATTO and RIBEIRO, 2009).

For effective application of FMEA, it is recommended that the engineer in charge of the analysis include representatives from all areas related to the process. This usually involves professionals in the areas of materials engineering, manufacturing, assembly, quality and technical assistance, in addition to the designers and engineers responsible for the processes directly involved, such as suppliers and customers. This interdisciplinary collaboration allows a broad and detailed view of possible failures, contributing to the robustness and reliability of the studied process (FOGLIATTO and RIBEIRO, 2009).

2.11 PARETO CHART

The Pareto Chart, or Pareto chart, is a quality tool represented by a vertical bar chart (columns), to order data in descending order of importance, with values presented as a percentage. Pareto usually includes a cumulative curve, making it easier to identify the most critical problems and help establish priorities for their resolution. The objective is to classify the causes of defects or non-conformities by frequency of occurrence, in order to direct efforts to the main causes (PEZZATTO et al., 2021).

Developed by Vilfredo Pareto in 1896, the diagram is based on the principle that most problems result from a small number of causes. These causes are divided into two groups: the "trivial" ones, which correspond to most occurrences, but with little impact, and the "essential" ones, which are less frequent, but have a very significant effect. This concept is also known as the "80-20 technique", in which 20% of the causes are responsible for 80% of the observed effects (PEZZATTO et al., 2021).

Joseph Juran adapted the Pareto diagram to apply it to quality problems such as machine failures, defective items, customer complaints, lost productivity, delivery delays, and workplace accidents. He classified the problems into "vital few", which are a few problems with a large impact, and "many trivial", which represent a large number of problems, but which do not cause significant impacts to the company. This adaptation demonstrates that most problems originate from a small number of causes, which, when identified and corrected, eliminate most defects. In this way, the Pareto Diagram separates the essential causes, which contribute to the 80% of the problems, from the trivial causes, responsible for 20% of the effects, explaining why this tool is known as the 80-20 technique (PEZZATTO et al., 2021).

2.12 ISHIKAWA DIAGRAM

The Ishikawa Diagram, also known as the Cause and Effect Diagram, was developed by Ishikawa in 1943 at the University of Tokyo. Its purpose was to demonstrate the interconnection between the various factors of a process. This diagram presents a set of causal factors associated with a quality effect, representing the relationship between an effect and all possible "causes" that can contribute to it.

This tool is widely used in quality management due to its simplicity and effectiveness in analyzing and identifying the main causes of variation in a process or the occurrence of problems. The diagram facilitates the understanding and search for solutions, by pointing out several influences that impact the process, allowing a systemic analysis of the whole. It is particularly useful for establishing relationships between opinions obtained in *brainstorming* sessions or other forms of data collection (PEZZATTO et al., 2021).

The Cause and Effect Diagram is a figure composed of lines and symbols that represent the relationship between an effect and its possible causes, facilitating the description of complex situations that could hardly be interpreted in words alone. Each effect is associated with several categories of causes, which can be subdivided into additional causes. The main categories are: method, labor, material, machine, environment, and measurements, known as the 6Ms (PEZZATTO et al., 2021).

3 METHODOLOGY

Following the parameters established by GIL (2002), this research regarding nature can be classified as an exploratory research.

The case study, according to the same author, is characterized by an in-depth analysis with specific objectives, providing a detail that would be difficult to obtain in studies with a greater number of variables. Considering that the objective of this research is specific and requires a detailed examination of the problem, this approach is adequate.

Due to the nature of the research, which involves both data collection and analysis, the results are presented in two forms: quantitative and qualitative. Quantitative analysis occurs through the collection, treatment, and analysis of operational data, with the support of Figures and pivot tables to organize and visualize information accurately. This approach allows the objective identification of failure frequencies and maintenance trends in the equipment. On the other hand, qualitative analysis focuses on the detailed observation of corrective maintenance processes and dialogues with the company's employees, with the aim of deepening the understanding of the underlying causes of failures and supporting the careful choice of the asset to be analyzed. This mixed approach provides a broad and grounded view of the practices and challenges present in the maintenance of the equipment under study.

Therefore, the method adopted in this research follows a mixed approach with an exploratory purpose. The theoretical foundation is based on biblioFigureic reviews on industrial maintenance, along with a specific case study, detailed in the introduction of this work. This methodological combination enables an in-depth analysis of the current maintenance situation in the company, with the use of quality tools to identify and categorize the main causes of failures.

3.1 MATERIALS AND METHODS

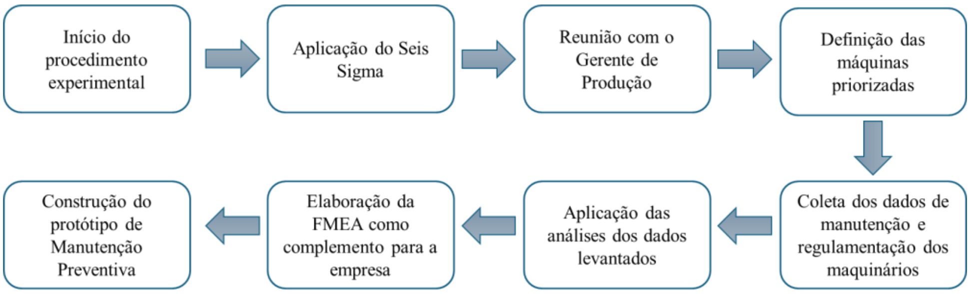
To ensure a systematic and efficient development of the analyses in this study, the methodology adopted was carefully planned to organize and guide each stage of the work with clarity and objectivity. The application of a structured method is essential in case studies, as it facilitates the understanding of the activities and contributes to the validation of the results (YIN, 2015).

The proposed methodology follows a set of logical steps, with the objective of establishing a sequence that ensures scientific rigor and allows the replicability of research, indispensable factors in projects aimed at optimizing industrial processes (GIL, 2002). Figure 1 presents the flowchart of the established steps, which serves as a guide in the execution of the work and provides an overview of the investigative process adopted.

In addition, each phase of the process is planned to capture essential information, identify patterns, and propose data-based interventions to impact the operational efficiency of the equipment studied. Thus, the methodology ranges from the careful choice of the asset, through the collection and analysis of operational data, to the proposition and validation of maintenance solutions.

Figure 1

Flowchart to identify the steps carried out in the Case Study



Source: The Author.

3.2 APPLICATION OF SIX SIGMA

The Six Sigma methodology, recognized for its rigor in continuous process improvement, uses the DMAIC cycle as a central analysis structure. This study fully applies this methodology, ensuring a systematic and well-structured approach. In the initial phase, of Definition, the equipment that makes up the scope of the analysis is identified, along with the main variables that justify its prioritization for this study.

In the Measurement phase, operational data is collected over a specific period, with strict attention to technical requirements, the recurrence of corrective maintenance, and the guidelines provided by the equipment manufacturers. To deepen the analysis of failure modes and their causes, quality tools such as the Ishikawa Chart and the Pareto Chart can be applied. Complementing this step, the Failure Modes and Effects Analysis (FMEA) tool is developed, in Excel, aiming to assist the company in standardizing and improving future maintenance routines.

In the Control phase, the focus is on the construction of a prototype preventive maintenance plan, designed for replication in other assets and for the improvement of the company's maintenance practices. This plan emphasizes the continuous monitoring and strategic management of maintenance activities, with the objective of reducing failures, increasing equipment reliability and ensuring the sustainability of operational performance.

3.3 DEFINITION OF THE ASSET STUDIED

To ensure a detailed and effective analysis, the development of the work is concentrated on a single asset. The selection of the asset to be studied takes place through a rigorous process, which involves meetings with the company's Production Manager. In these meetings, the main bottlenecks related to operational failures, intervention priorities and the impact on production are discussed. Based on a thorough analysis of the information collected, *the Slitter* equipment is defined as the main focus of this study.

3.4 DATA COLLECTION AND TABULATION

The data collection for this study occurs directly in the business environment, with the objective of subsidizing analyses in different stages of the process. In the data collection phase, the historical records of corrective maintenance performed over a specific period, the maintenance performance indicators monitored so far, and the characteristics of the asset under study, including regulations and standards provided by the equipment manufacturers, are considered. This approach is critical to understanding maintenance requirements and recommended timelines for performing repairs.

In the initial assessment, the descriptions of failures in each corrective maintenance are checked and grouped according to the type of service performed. This data is organized and presented in a Pareto chart, allowing a hierarchical visualization of the most relevant and frequent occurrences in the maintenance process. With this tool, the Pareto principle is applied, suggesting that 80% of problems stem from 20% of root causes, which makes it easier to prioritize efforts for improvement.

The most significant occurrences identified in the Pareto Chart serve as the basis for further analysis, using the Ishikawa Diagram (or Cause and Effect Diagram). This method makes it possible to identify the root causes of the most recurrent failures, providing a solid basis for implementing improvements in the maintenance process, with a focus on increasing operational efficiency and reducing equipment downtime.

3.5 PREPARATION OF THE FMEA

There are several versions and formats of forms for the application of FMEA, and the organization must select or design the one that best suits its specific needs and criteria. Despite this flexibility, the fundamental elements remain constant in all versions. These elements include: header, functions, failure modes, effects, severity, causes, occurrence, controls, detection, and recommended actions (PALADY, 2004).

FOGLIATTO and RIBEIRO (2009) suggest a form to accompany the FMEA process containing the following fields:

- Header: Includes identifying information for the study, such as the FMEA number, the process analyzed, the responsible department, the participants, and the date.
- Item/Function: Describes the operation or function under analysis, with the purpose or requirement to be met.
- Potential Failure Modes: Lists the possible non-conformities associated with the item studied.
- Potential Failure Effects: Defines the defects that arise as a result of failure modes.

- Severity (S): Qualitatively evaluates the impact of the failure mode on the system, on a scale of 1 to 10, so that 1 means a mild effect and 10 means a very severe effect.
- Classification: Can be used to classify any characteristic of the operation that may require special control.
- Potential Causes/Mechanisms of Failure: Specifies the causes or mechanisms that generate the failure mode, in a clear and detailed manner.
- Occurrence (O): Measures the probability of the cause occurring, also on a scale of 1 to 10, with 10 being the highest probability.
- Prevention and Detection Control: Records existing controls to prevent or detect failures.
- Detection (D): Evaluates the effectiveness of controls in detecting failures, on a scale of 1 to 10, where 10 indicates a lower chance of detection.
- Risk (R): The total risk of the failure mode is calculated as the product of severity, occurrence, and detection in order to prioritize corrective actions.
- Recommended Actions: Improvement actions are proposed based on the prioritization of the identified risks.
- Responsible and Date (for the action): The individual responsible for the recommended action is indicated, as well as the target date to complete the task.
- Actions Taken: Brief description of the corrective and improvement actions effectively implemented.
- Resulting Risk (R): Refers to the assessment of future risk based on severity, occurrence, and detection, after identifying corrective actions, but before implementing them.

The FMEA form is a dynamic document, that is, constantly evolving, that must incorporate the most recent versions of the project or process, as well as the actions taken, even after the start of production. In this way, a record of the implemented changes and an updated assessment of the risks related to the project or process in question are kept (FOGLIATTO and RIBEIRO, 2009).

4 DATA, RESULTS, ANALYSIS

This work aimed to structure the basis for the proposition of the development of a Preventive Maintenance Plan directed to *Slitter*, a critical machine in the operation of the company studied. Due to time constraints, priority was given to the elaboration of a prototype of the plan, focusing on the analysis of historical corrective maintenance data and the application of quality tools to support decision-making.

4.1 CONTEXTUALIZATION OF THE COMPANY'S SCENARIO

The company subject to this case study faces significant challenges in its maintenance management, especially in relation to the *Slitter*, an imported machine with approximately 40 years of operation. Essential for the company's production process and revenue, *Slitter* is obsoletic in several electrical and electronic components, which, added to the difficulty of replacing parts in the market, raises the level of risk and worries management about the operational reliability of this equipment. Given Slitter's strategic importance, a prolonged failure would have considerable impacts on production, which is why the company is currently seeking budgets for the modernization of electrical panels (*Retrofit*) from three specialized suppliers. This upgrade, however, requires high investments and an estimated downtime of 30 days, which poses an additional challenge to maintenance planning.

The company's maintenance sector, structured with strong *expertise* and composed of an electrical and electronic engineer and a mechanical maintenance technician with four decades of experience, follows the guidelines of the ISO 9000 Procedure (PQ 7.1.3). This protocol requires that all maintenance – whether preventive, corrective, or process improvements – be formalized via Service Orders (O.S.), ensuring the detailed record of activities and allowing the compilation of essential metrics, such as MTBF, MTTR, and DF. However, the reliability of these indicators is still below expectations due to the lack of a fully structured preventive process and a preventive maintenance schedule that aligns with production demands.

Currently, the preventive maintenance schedule faces difficulties in its execution, often hampered by the high volume of production, which reduces the time available for complex preventive interventions, carried out only quarterly, during inventories. Essential preventive actions, such as lubrication and bearing checks, are scheduled for times that minimize the impact on the operation, such as Saturdays and periods coordinated with production supervision. In parallel, spare parts inventory management represents another critical point, since the formation of a complete inventory is financially unfeasible, especially for imported parts. To mitigate downtime and ensure operational continuity, the company maintains a partial inventory of critical items, although this arrangement does not fully meet maintenance demands.

Given this scenario, the need for a preventive maintenance plan becomes evident, aiming to ensure the availability and continued performance of *Slitter* and other critical assets.

The development of this prototype, although it does not represent a finalized plan, establishes a solid basis for the implementation of preventive actions in the future, seeking to promote a cultural change in the company, directed to a more preventive and less reactive posture in the face of industrial maintenance challenges.

4.2 ACTIVE INGREDIENT STUDIED

To ensure a careful analysis and propose effective solutions, the study was directed to the evaluation of a specific equipment. In this context, meetings were held with the company's Production Manager, aiming to understand the main bottlenecks related to operational failures, as well as to define intervention priorities.

After analyzing the information collected, the *Slitter* equipment was selected as the main focus of this study. This choice is based on its relevance to the production process, in addition to its direct impact on the company's revenue, which makes the optimization of its operation essential for improving efficiency and competitiveness.

Slitter, also known as a slitting line or rotary shear, is a critical piece of equipment in the operations of the branch company studied. Manufactured in 1982 by Braner USA Inc. and equipped with General Electric propulsion engines, it performs the vital function of cutting steel coils into strips of different thicknesses and widths, accounting for approximately 80% of the cut steel production, with an average of 2,800 tons per month.

This equipment has significant capacities, with an input shaft supporting up to 14 tons and an output shaft with a capacity of 10 tons. Its maximum cutting speed is 300 meters per minute, with nominal cutting tolerances of +/- 0.20 mm, which makes it essential to meet the strict quality standards required in the sector.

In addition, *Slitter* utilizes a set of specific knives that require regular maintenance, such as grinds, to ensure cutting efficiency. Given its central role in operations and the need for proper maintenance to avoid failures and interruptions, the preparation of a preventive maintenance plan becomes essential to optimize its performance and ensure the company's operational continuity. Figure 2 illustrates the *Slitter machine* in operation, performing its sheet metal cutting activities.

Figure 2

Slitter's working process

Source: The Author.

4.3 DATA COLLECTION AND PROCESSING

Initially, a meeting was held with the company's Production Manager to clarify the purpose of the study and align expectations in relation to the desired results. This meeting enabled a deep understanding of the corrective maintenance process applied in the production context.

From this meeting, historical data on maintenance carried out at *Slitter* between January 2023 and September 2024 were extracted. These data included both corrective and preventive maintenance, with the aim of understanding the distribution and frequency of each type of intervention. From this base, a percentage analysis was performed, revealing that only 11% of the maintenance was preventive, while 89% corresponded to corrective maintenance, which evidenced the predominance of corrective actions. As the focus of the work is on the analysis of corrective maintenance for the construction of the prototype, the data was treated using only the records of this type of maintenance.

After proper data treatment, 54 corrective maintenance were identified, of which 47 were valid for subsequent analyses. Of this total, 21 maintenance (44.7%) are of an electrical nature and 26 (55.3%) of a mechanical nature. The remaining 7 maintenances were excluded after alignment with the electrical and mechanical teams. This decision was made because some historical maintenance, because they are older, did not reflect the current reality of the operation due to the replacement of equipment or changes in the process. Therefore, these maintenances were not relevant for the construction of a future preventive plan.

4.4 CORRECTIVE MAINTENANCE GROUPING

Subsequently, a meeting was held with those responsible for the Electrical and Mechanical areas, in order to understand in depth the failures corresponding to each intervention. With this information, maintenance was grouped into seven groups for Electrical and nine for Mechanical. This grouping facilitated analysis and allowed the identification of similar failures that could be addressed jointly in future corrective maintenance.

Chart 1 presents the classification of corrective maintenance services, divided between the areas of Electrical and Mechanical. The Electrical area is composed of 7 groups, which, together, include a total of 21 distinct faults. In turn, the Mechanics area covers 9 groups, adding up to 26 different failures. Thus, the total number of failures identified in the database for the period studied is 47, resulting from the sum of the failures of the two areas.

Table 1

Grouping of Corrective Maintenance

Manutenções Corretivas	Contagem de Descrição do Defeito/ Falha
⊟ Elétrica	**21**
Drive (acionamento do motor Conversor de corrente)	7
Fim de curso/ sensor	2
Placas de controle (amplificador)	4
Revisão elétrica	2
Revisão/ correção desgaste de cabo	4
Verificação de botões (hidráulico)	1
Verificação/ Substituição Contator	1
⊟ Mecânica	**26**
Lubrifil/ regulador (Conjunto pneumático)	4
Preventiva de mancal do rolo da mesa	1
Regulagem de corrente (Semanal)	5
substituição pino elástico	2
Troca de parafuso mandril	2
Verificação Cilindro Hidráulico	3
Verificação da mangueira e conexões	5
Verificação/ troca da Gaxeta da porca	2
Verificar nível dos tanques	2
Total Geral	**47**

Source: The Author.

4.5 APPLICATION OF THE PARETO CHART

From the grouped data, the Pareto Diagram was elaborated, separately for the groups of electrical and mechanical failures, in order to identify the most recurrent corrective maintenance services in each area. This analysis allowed us to highlight the most critical services, providing a basis for prioritizing future failure analyses.

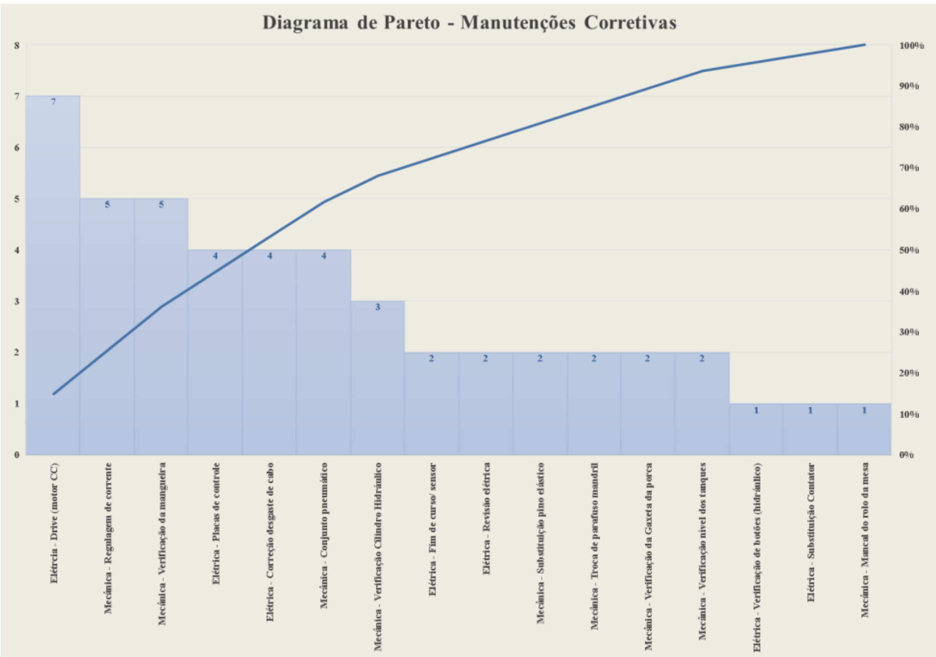
Figure 3 shows the Pareto Chart for the services in the Electrical and Mechanical areas. To construct the Figure, a bar Figure was used in which the X-axis shows all the corrective maintenance service groups listed in Chart 1. The members have been arranged in descending order, so that each maintenance group is represented by the number of defects/faults associated with it. On the Y-axis, there is the total failure count, which determines the height of each bar.

In addition to the bars, the chart includes the Pareto curve, visually highlighting the most significant problems. The curve indicates the cumulative percentage of failures, allowing the identification of the 20% of maintenance groups that correspond to approximately 80% of the problems, according to the Pareto principle.

Thus, it was identified that the most critical group in the Electrical area is the *Drive* (DC motor), with a total of 7 occurrences of failures in the analyzed period. In the area of Mechanics, the most critical groups are Current Adjustment and Hose Checking, both with 5 occurrences each. This data highlights the main points of attention to optimize maintenance and reduce recurring failures in the respective areas.

Figure 3

Pareto Diagram of Corrective Maintenance at Slitter



Source: The Author.

4.6 DOWNTIME ANALYSIS

In addition to evaluating the frequency of occurrences, an analysis of corrective downtime by service group was carried out, both for the Electrical and Mechanical areas.

This analysis made it possible to correlate the impact of each failure, considering not only its frequency, but also the time required for each intervention, which reinforces the criticality of certain services and guides prioritization in the development of preventive maintenance solutions.

Figures 4 and 5 show the relationship between the total corrective downtime and the services performed, each one specific to a maintenance area: Electrical and Mechanical. Both have the same purpose and format, differing only in terms of the specific data of each area. In each Figure, the bars represent the different groups of corrective maintenance services listed in Exhibit 1, and each percentage reflects the cumulative downtime of failures in that group relative to the total downtime of the entire area.

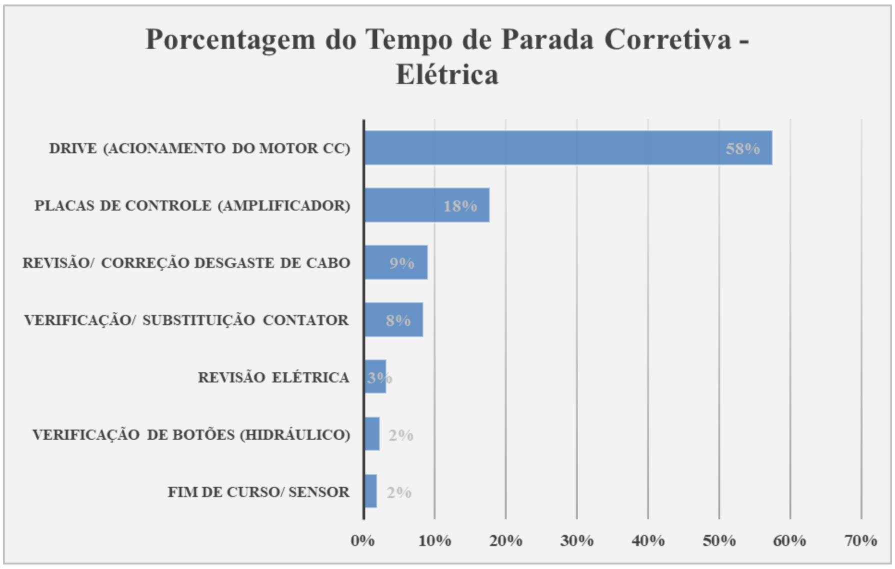
In the analysis of the Electrical area, it is observed that the total corrective downtime over the analyzed period was 25 hours and 55 minutes, distributed among 21 corrective interventions performed, corresponding to the 7 different groups of services. Among these groups, the most critical, in terms of impact on downtime, was *Drive*, related to the drive of the Current Converter motor. This group totaled 14 hours and 55 minutes of downtime, which represents 58% of the total corrective downtime of the Electrical area, thus standing out as the main point of attention for possible improvements and preventive actions. This percentage reflects the relevance of *Drive* not only because of the frequency of occurrences, but also because of the prolonged recovery time needed to restore the operation, characterizing it as one of the priority services in the search for optimizations in the maintenance plan.

For the Mechanics area, the total corrective stop time in the period was 28 hours, encompassing 26 interventions distributed in 9 service groups. The analysis reveals that the group with the greatest impact on downtime was Elastic Pin Replacement, whose accumulated time was 9 hours and 20 minutes, representing 33% of the corrective downtime in the Mechanical area. This representativeness indicates that, although other groups also require attention, Elastic Pin Replacement is a critical activity that deserves specific planning to reduce downtime and mitigate future failures.

The comparative analysis between Figures 2 and 3 allows us to visualize, in a clear and segmented way, the differences in downtime between the Electrical and Mechanical areas, evidencing the groups that most impact operational continuity. Therefore, it can be seen that, in the Electrical area, the *Drive* group (Drive of the Current Converter motor) had the longest downtime in the period studied, representing 58% of the total and standing out as the most critical. In the Mechanics area, the Elastic Pin Replacement group had the longest downtime, corresponding to 33% of the total. This data indicates the groups that deserve priority attention to optimize uptime and reduce disruptions caused by corrective failures.

Figure 4

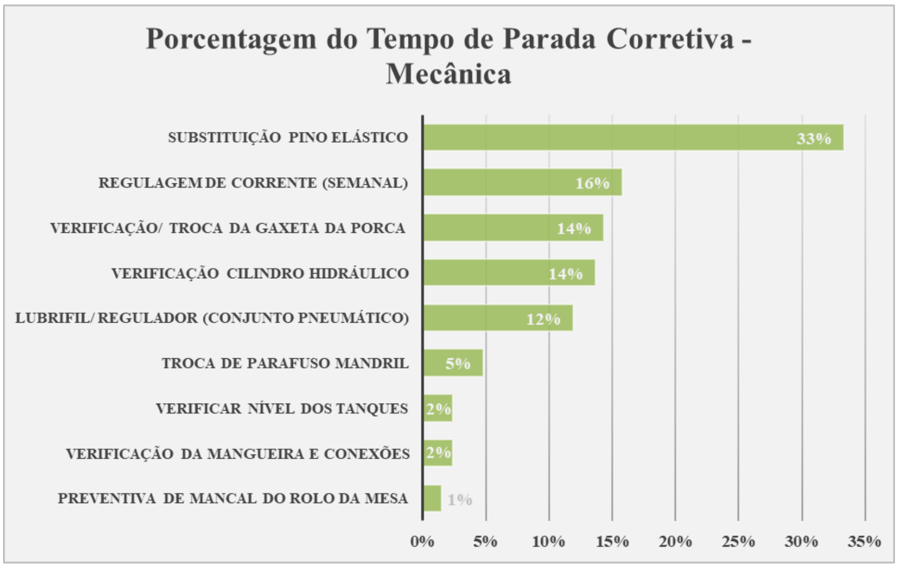
Percentage of Electrical Downtime



Source: The Author.

Figure 5

Percentage of Mechanical Downtime



Source: The Author.

4.7 IDENTIFICATION OF CRITICAL GROUPS

By relating the data on frequency and downtime, it was possible to identify the services with the greatest impact on the production process. In the case of the Electric Chain, the group related to the *Drive* (drive of the current converter motor) was chosen, as it represented 58% of the downtime of the electrical corrections, in addition to being the group with the highest number of failures (7 occurrences) in the analyzed period.

In the Mechanical area, two groups stood out: Chain Adjustment and Elastic Pin Replacement. These two groups together corresponded to 49% of the downtime of the mechanical correctives, totaling seven failures in the analyzed period. After discussion with the Production Manager, it was decided that the focus would be on Current Regulation, as it is a component of greater complexity and impact on the operation.

4.8 ROOT CAUSE ANALYSIS: ISHIKAWA DIAGRAM

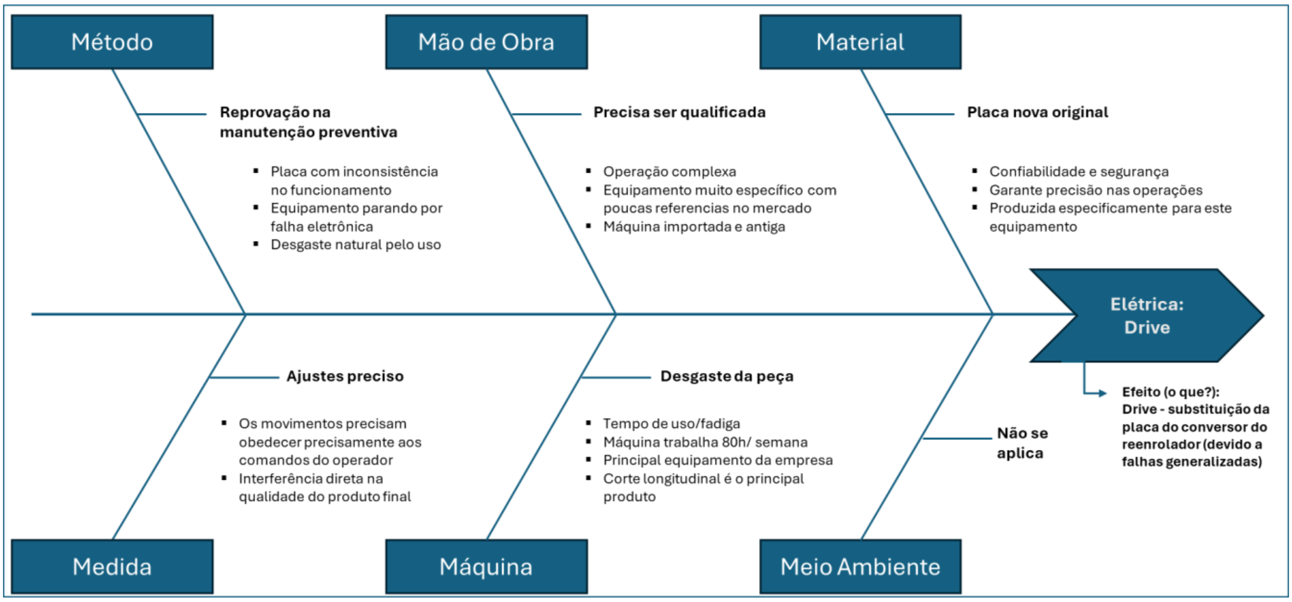
For each group of critical corrective services identified, an Ishikawa Diagram was developed, in order to analyze the main causes that led to the recurrent failures. The first diagram was prepared for the Electrical area, focusing on Drive (Drive of the Current Converter motor). The effect would be the replacement service of the rewinder converter plate. The causes identified involved factors such as wear and tear of the part, lack of effective preventive maintenance, need for qualified labor and specific material for replacement. Figure 6 shows the Ishikawa Diagram for the *drive*.

In the Mechanical area, the diagram was developed for the Chain Adjustment of the carriage transporter of the cut strips. The causes identified include deregulation of the traction system, the need for precise adjustments and technical qualification of the maintenance team. Figure 7 shows the Ishikawa Diagram for current regulation.

The Ishikawa Diagrams were prepared with the collaboration of the Production Manager, ensuring a more accurate analysis of the causes of failures. These diagrams serve as a fundamental tool for structuring a future preventive maintenance plan, as they identify not only the immediate causes, but also the underlying causes, allowing for effective corrective actions.

Figure 6

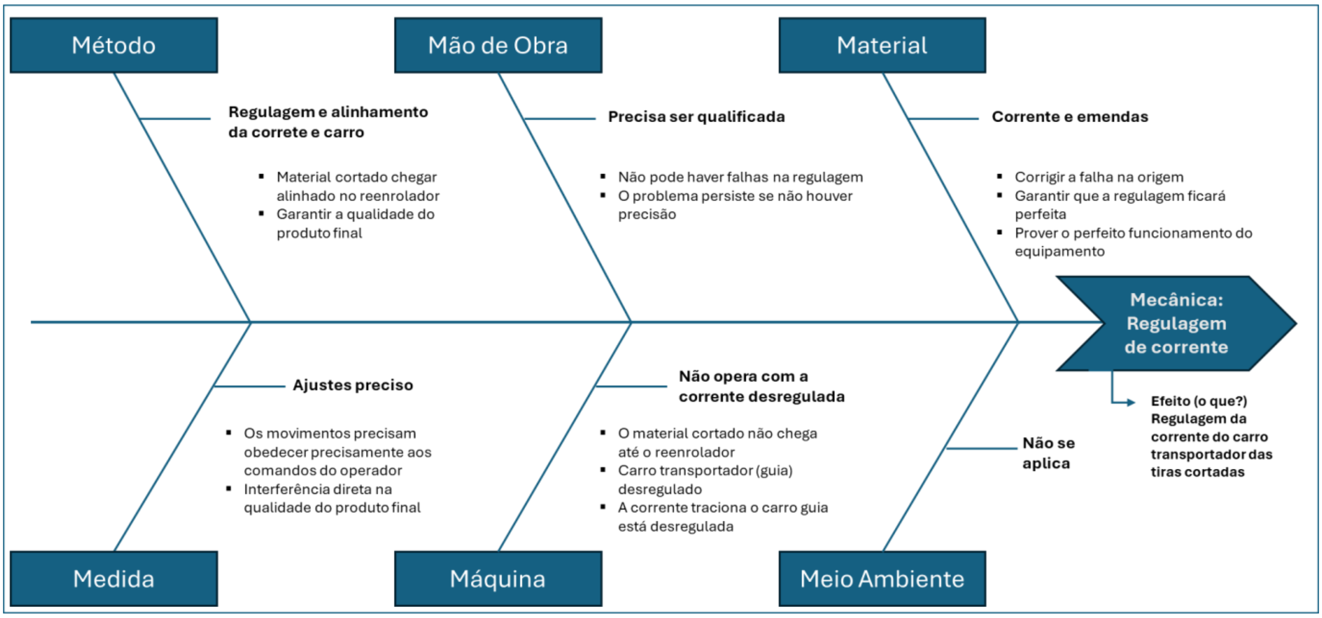
Ishikawa Electrical Diagram



Source: The Author.

Figure 7

Ishikawa Mechanics Diagram



Source: The Author.

5 FINAL THOUGHTS AND CONCLUSIONS

The present study reinforces the importance of structured maintenance planning to ensure greater assertiveness in interventions, reduction of operational failures, reduction of downtime and cost optimization. The formulation of a Preventive Maintenance Plan, based on rigorous data analysis methodologies, becomes essential for the continuity and efficiency of operations, especially when it comes to critical equipment, such as *Slitter*.

The use of quality tools, notably the Pareto Chart and the Ishikawa Chart, proved to be of great value for the identification and prioritization of critical points of failure. Such tools provided a detailed analytical approach, allowing the elaboration of an accurate diagnosis of the factors that negatively influence the performance of the equipment. Thus, the proposed solutions acquire a robust technical character and are based on empirical evidence, which favors the implementation of a more effective maintenance plan directed to the most relevant components.

Although the integral development of a Preventive Maintenance Plan was not feasible within the limited temporal scope of this study, the prototype elaborated establishes a consistent and replicable framework. The proposed methodology allows the analyses outlined here to be expanded to other areas and equipment of the company, promoting a systematic and comprehensive approach to maintenance management. Thus, it is expected that the present work will work as an initial model, enabling its later application in other contexts, in addition to contributing to the evolution of the company's internal practices.

In addition, an Excel spreadsheet was prepared for the construction of FMEA (*Failure Modes and Effects Analysis*), in order to complement the diagnosis of failures and expand the understanding of the underlying causes of corrective maintenance. Although FMEA has not been applied in the scope of this study, its inclusion offers a significant future step for the company. The systematic application of this tool will make it possible to identify potential failure modes and prioritize corrective actions in a more assertive way, with a focus on preventing failures in critical equipment. The adoption of FMEA as part of the maintenance analysis routine will facilitate the understanding of the severity and frequency of failures, promoting a process of continuous improvement and a culture oriented towards anticipating problems and mitigating risks.

The adoption of these practices highlights the need for a cultural change within the organization, with regard to maintenance management. The predominance of reactive approaches, which aim to correct failures only after they occur, proves to be ineffective in the long term, resulting in increased operating costs and longer downtime. In this sense, the transition to a preventive maintenance model, supported by quality tools, will enable more predictive and proactive management, in which potential failures can be identified and mitigated before they result in interruptions or significant damage.

In addition, the replication of the proposed methodology for the other equipment of the organization can promote an integrated and strategic management of maintenance, based on careful analysis and standardized processes. The continuity of this process depends, to a large extent, on the training of the maintenance team, which should be able to apply the methods of analysis and investigation of failures developed throughout this study. Such training will ensure that the company can autonomously proceed in the execution and finalization of the Preventive Maintenance Plan, resulting in more assertive and reasoned decision-making.

After the implementation of the Preventive Maintenance Plan, it is recommended, for control and monitoring, the application of maintenance indicators mentioned in the theoretical framework — such as MTBF (*Mean Time Between Failures*), MTTR (*Mean Time to Repair*) and DF (Physical Availability). These indicators make it possible to evaluate the effectiveness of the process and identify possible bottlenecks in the plan. In the case of the company studied, which already has a historical basis of these indicators, it is planned, as a future work, to carry out a comparison of the results obtained in order to measure the impact of the new plan.

In conclusion, this work offers a significant contribution to the improvement of the company's maintenance management. The methodology developed proposes a clear path to reduce failures and costs, but also offers a strategic and long-term vision for asset management, which may result in greater competitiveness, operational efficiency and asset reliability.

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