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Comparative Analysis of the Resources Applied to Corrective and Preventive Maintenance in an Industrial Refrigeration System: Impacts On Production Efficiency

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ABSTRACT: Maintenance of industrial systems, especially in meatpacking plants, is essential to ensure operational efficiency and financial viability. The paper addresses the need to evaluate and compare the resources invested in planned and unplanned maintenance, with the aim of identifying whether investment in preventive maintenance contributes to increased production efficiency. The topics covered include industrial operations, maintenance in industrial operations, corrective and preventive maintenance. The research is classified as quantitative and descriptive, using a literature review and documentary research, with a study in a beef slaughterhouse located in the southeast region of Mato Grosso do Sul. The results showed that the increase in preventive maintenance practices had a positive impact on the organization's production efficiency, showing significant operational improvements. This reinforces the importance of a preventive approach to resource management and the stability of industrial operations.

Key words: Corrective maintenance, preventive maintenance, resources, efficiency.

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1. INTRODUCTION

Maintenance of industrial systems, especially in meatpacking plants, is crucial to ensure operational efficiency, safety and financial viability Due to the complexity and challenging environment, a thorough approach is essential to prevent catastrophic failures, avoiding downtime, product losses and high repair costs

Large corporations, in the view of Kardec and Nascif (2009), need to adopt a strategic approach in their decision-making and actions, where improving the reliability and availability of equipment brings advantages such as increased turnover, profit and safety, reduced demand for services and operating costs, as well as environmental conservation and extending the useful life of equipment.

According to Seleme (2015), correctly adjusted equipment consumes fewer resources, shows less wear and tear, maintains predictable productivity levels and requires less frequent reinvestment. The author also states that these factors highlight the importance of organizations, in collaboration with their production processes, planning maintenance strategies, either internally or through outsourcing.

Planned maintenance, according to Almeida (2016), involves regular, scheduled interventions to inspect, adjust, repair or replace components before they fail, while unplanned maintenance occurs in order to immediately

deal with a breakdown, often leading to prolonged downtime and emergency repairs, which tend to be more expensive and disruptive. It should be noted that in the meatpacking industry, even small problems with machinery could result in significant losses, affecting the competitiveness of the sector, which deals with perishable and delicate products.

Against this backdrop, the central research problem of this study lies in the need to evaluate and compare the resources associated with planned and unplanned maintenance in a beef slaughterhouse industrial system. Based on this research problem, the research objective was to identify whether investing in preventive maintenance contributes to increasing production efficiency in the industry analyzed.

Once this research has been completed, the results generated are of great importance to managers and maintenance engineers in the industrial meatpacking sector. They provide a detailed analysis of the resources associated with planned versus unplanned maintenance, highlighting the effectiveness of preventive strategies in reducing operating expenses and optimizing system efficiency. These findings have the potential to guide strategic decisions and asset management policies, promoting more efficient and cost-effective practices in the industry.

Mwanza et al. (2022) point out that the evaluation of effectiveness is essentially related to how well the organization matches its products or services with the identified needs of its customers. In the authors' conception, this is important to apply to the activities that critically support the competitive strategy and should be a means of clearly establishing the value drivers for each of these activities.

For a better presentation of the data, this article has been divided into five different sections: section one presents a contextualization, the objectives and importance of the research, section two presents bibliographical references that clarify and guide the research, section three presents the methodology used to achieve the results, section four presents the data researched and the analyses carried out and, finally, section five presents the final considerations drawn from the study.

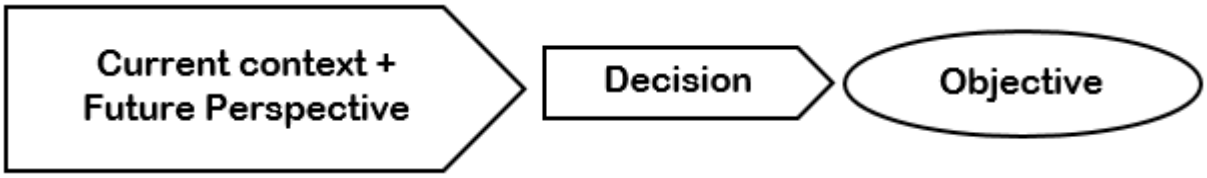
2. INDUSTRIAL OPERATIONS

Operations are activities that transform inputs into products or services, points out Luz (2015), and can involve processing information, materials or consumers. The author also states that sectors such as purchasing, sales, production, services, human resources and logistics are examples of business operations. He goes on to say that, production management is an ancient practice, but gained prominence in the Industrial Revolution, when its study and evolution accelerated.

Production management techniques, initially developed for industry, were gradually applied to other organizations, such as commercial and service providers. Regardless of size, Slack, Brandon-Jones and Johnston (2018) state that all companies need to create and deliver their services and products efficiently and effectively, optimizing their operations by managing resources efficiently, increasing revenues, making strategic investments and progressively improving their skills. The author goes on to say that, all managers, regardless of their role, have something to gain from studying the principles, concepts, approaches and techniques of production management.

Guidelines and decisions must be made based on the competitive dimension in which the company chooses to operate, according to Luz (2015), and in order to be competitive, the company must seek competitive advantages in the competitive business environment in which it operates One of the most significant of these, according to Moreira (2012), is the need for companies to adapt to increasingly complex environments Although it is impossible to predict which companies will dominate the market in the coming decades, as Neumann and Scalice (2015) point out, those that aim to be competitive must make a continuous and systematic effort It is essential that they improve their formal processes for planning, decision-making and developing production systems Figure 01 shows how analysis of the current context in conjunction with a future perspective guides decisions which, when taken well, lead to the achievement of planned objectives.

Figure 01 - Planning



Source: Corrêa; Gianesi; Caon, 2010. Adapted.

The way an operation manages the transformation resources needed to produce the required types and quantities of its products and services will also have a strategic impact Operations that are well planned and executed, in the view of Slack, Brandon-Jones and Johnston (2018) are less likely to fail In the author's view, this means that they are likely to operate with a predictable and acceptable failure rate, without disappointing their customers or incurring excessive costs.

According to Slack, Brandon-Jones and Johnston (2018), effective cost management in production is not just limited to direct price competitiveness, but permeates all business operations. The author also points out that the strategic allocation of operational resources in areas such as personnel, infrastructure, technology and equipment not only directly influences costs, but also significantly influences the organization's ability to optimize its operations and sustain competitive performance in the long term. He concludes by saying that this approach not only strengthens the company's financial position, but also reinforces its ability to adapt and innovate in the face of a dynamic and demanding market.
Innovation, in Zavatins's et al. (2024) conception, has gained important positions in public and private organizations' agendas in recent years. In this case, innovation drives more productivity, efficiency, and competitiveness.

2.1 Industrial operations maintenance

Since the beginning, according to Almeida (2016), human beings have always been concerned about the environment around them, creating tools to facilitate activities, and the need arose for preservation, repair and replacement, practicing maintenance in a rudimentary way The advance of manufacturing led to the development of numerous inventions for machines, according to the author, which created the need for more effective maintenance methods, capable of repairing damaged equipment and preventing unexpected failures.
The organization of maintenance, as pointed out by Bueno (2020), had its initial milestone in European and North American countries, where the idea of structuring maintenance arose, possibly due to the age of their industrial parks. It was in these places that the terms maintenance, manutention and upkeep first appeared.
According to Terra (2011), maintenance means the act or effect of maintaining. Maintenance encompasses the upkeep of all equipment, Bueno (2020) says, ensuring that it is in optimum operating condition when needed.
From the perspective of Xenos (2014), it is common for some people to use the term "maintenance" more narrowly, associating it only with repairing or fixing equipment, which can end up reducing the full concept of maintenance. The author goes on to say that maintenance activities should include modifying the original condition of equipment by implementing improvements, with the aim of preventing recurring failures, optimizing resources and improving productivity. Table 01 shows the evolution of maintenance over time, highlighting the transition from repairs after failures to preventive approaches.

Table 01 - Evolution of maintenance

	First Generation (before 1940)	Second Generation (1940-1970	Third Generation (1970-1990)	Fourth Generation (from 1990)

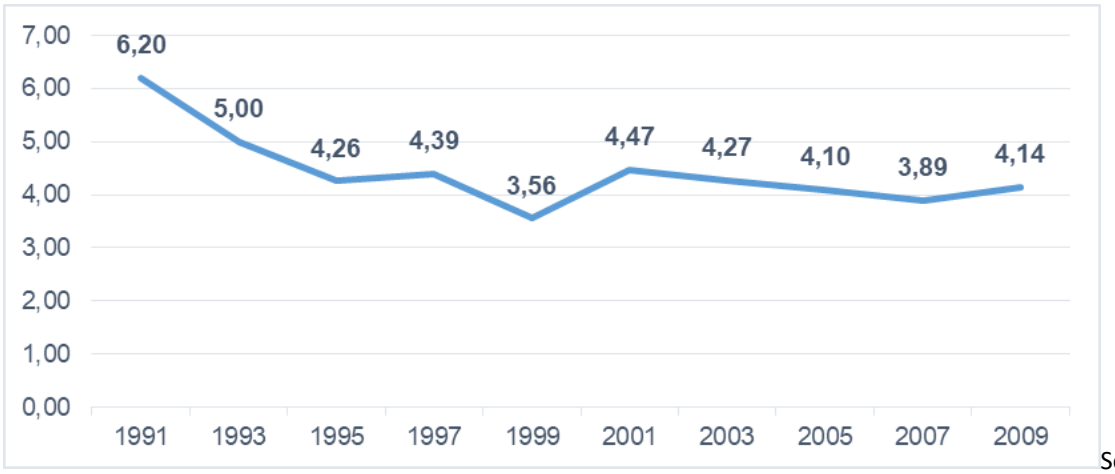
Increased expectations regarding Maintenance	- Repair after failure	- Increased availability - Longer equipment life	- Greater reliability - Higher availability - Better cost-benefit ratio - Preservation of the environment	- Greater reliability - Greater availability - Preservation of the environment - Safety - Influence on business results - Asset management
Vision of equipment failure	- All equipment wears out with age and therefore fails	- All equipment behave according to the bathtub curve	- Existence of 6 failure patterns	- Drastically reduce premature failures of patterns A and F
Changing maintenance techniques	- Repair-oriented skills	- Manual maintenance planning - Large, slow computers - Preventive maintenance (by time)	- Condition monitoring - Predictive maintenance - Risk analysis - Small, fast computers - Powerful software - Multidisciplinary working groups - Reliability-oriented projects - Contracting for labor and services	- Increased Predictive Maintenance and Condition Monitoring Monitoring - Minimization of Maintenance Preventive and Corrective Maintenance - Failure Analysis - Reliability techniques - Maintainability - Maintenance Engineering - Projects focused on reliability, maintainability and Life Cycle Cost - Contracting for results

Source: Kardec e Nascif, 2009. Adapted.

Despite significant advances in the effectiveness of equipment maintenance, Seleme (2015) states that the maintenance of equipment and systems still faces several challenges. Among the main factors cited by the author are: size, cost, complexity, quality, competition and continuous improvement to overcome these difficulties and ensure the reliability and efficiency of systems. Thus, the so-called Maintenance Management was developed, according to Almeida (2016), a detailed field of study that covers strategies and methods from project conception to the actual use of machinery and equipment. It is based on ISO 55000, which was developed to guide maintenance practices.

The importance of maintenance is highlighted by various aspects, where until recently, as Moro and Auras (2007) point out, middle and corporate management did not consider the impact of maintenance on product quality, production costs and, above all, basic profit. However, the author also states that with the development of modern management techniques and maintenance systems, this perception has changed, leading to a reduction in maintenance costs in proportion to turnover. Kardec and Nascif (2009) point out that the overall average cost tends to stabilize over time, as shown in Graph 01.

Graph 01 - Maintenance costs in relation to gross sales



Source: Kardec e Nascif, 2009. Adapted.

When maintenance is properly planned, says Branco Filho (2008), with tasks carried out by qualified workers, there is an increase in equipment availability, an extension of useful life and a reduction in specific costs. The author concludes that maintenance management is encouraged to reduce its resources, which influences the company's overall costs, requiring the implementation of more effective working methods and improved techniques.

2.2 Corrective Maintenance

Corrective maintenance, according to Monchy (1989), is defined as maintenance carried out after a failure. After the First World War, Branco Filho (2008) points out that industry recognized the growing need to carry out maintenance to deal with problems such as machine breakdowns and stoppages, which resulted in the implementation of Corrective Maintenance. The author also states that this scenario intensified during the Second World War in the 1930s, when there was greater pressure to increase production and meet targets, leading maintenance teams to prioritize the rapid resolution of faults and the prevention of future problems in critical equipment.

Corrective maintenance, according to Kardec and Nascif (2009), can be divided into planned corrective maintenance and unplanned corrective maintenance. The authors state that unplanned corrective maintenance can also be called emergency maintenance, as it deals with failures or underperformance, without time for preparation and entails high costs. Planned work, on the other hand, the authors conclude, involves correcting an underperformance or failure, based on a management decision, involving cheaper work.

Sometimes, Almeida (2016) points out, even if we act as quickly as possible, we cannot avoid the losses resulting from an unplanned stoppage. He goes on to say that, these losses can involve idle employees, delays in production, purchasing parts without proper price research and mechanical work carried out under pressure. It is essential to point out that, although corrective maintenance can be considered advantageous in certain situations, according to Xenos (2014), we must not accept failures as inevitable, and it is crucial to identify and eliminate the root causes of failures in order to prevent their recurrence.

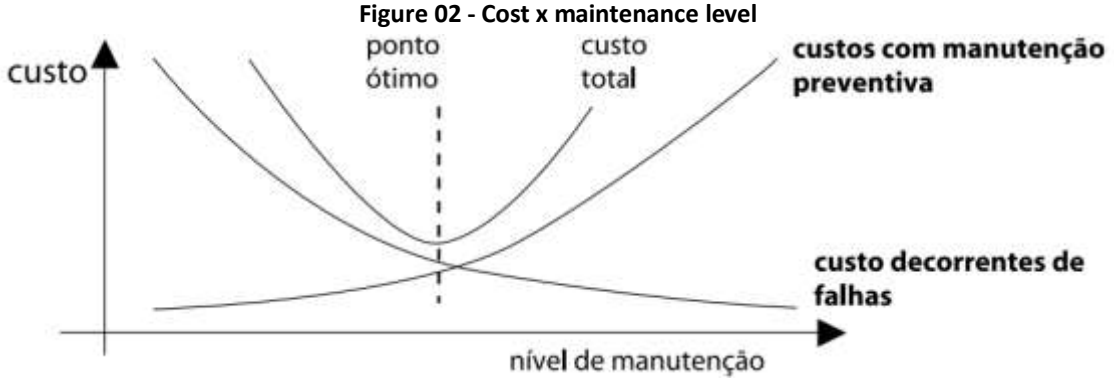
2.3 Preventive Maintenance

After the Second World War, Luz (2015) points out that advances in industry resulted in a growing demand for faster and more reliable production, making corrective interventions inadequate to satisfy a market increasingly eager for consumption. The author also states that, with the spread of computers and the strengthening of National Maintenance Associations, Maintenance Engineering adopted more sophisticated criteria based on conditions, integrated with automated planning and control systems, reducing bureaucracy in the execution of maintenance services.

According to NBR-5674 (2012), preventive maintenance involves carrying out services planned in advance, taking into account the needs of users, the expected durability of building systems and components, the severity and urgency of situations, as well as periodic reports assessing the state of degradation of equipment. According to Slack, Brandon-Jones and Johnston (2018), this strategy seeks to prevent or minimize the likelihood of failures through maintenance tasks such as cleaning, lubrication, replacement and inspection of installations, carried out at previously established intervals.

Considering maintenance as a principle for reducing production costs, Marcorin and Lima (2003) state that it is crucial to determine the most effective policy for optimizing these costs. This analysis can be seen in the graph in Figure 02, which shows the relationship between preventive maintenance costs and the costs resulting from failures.

Figure 02 - Cost x maintenance level



Source: Mirshawa & Olmedo, 1993.

One of the main advantages of preventive maintenance, according to Seeling (2000), is to avoid waste and losses resulting from unexpected breakdowns, which are one of the most unwanted situations in day-to-day production. Although initially more expensive due to the early replacement of parts and refurbishment of components, according to Xenos (2014), it reduces the frequency of failures, increases the availability of equipment and minimizes unscheduled interruptions in production, making it many times more economical than corrective maintenance when considering the total cost.

3. METHODS

This research is classified as quantitative. The adoption of a quantitative or positivist paradigm, according to Richardson et al. (2012), results in the choice of methods that use structured data collection instruments, as well as involving quantification both in obtaining the information and in analyzing it using statistical techniques.

In terms of objective, this research is classified as descriptive, because according to Gil (2002), the main objective of descriptive research is to describe the characteristics of a given population or phenomenon, or to establish relationships between variables. Many studies fall into this type of research and one of its distinctive features is the use of standardized data collection techniques, such as questionnaires and systematic observation.

In order to achieve the proposed objective, bibliographic research was first used. According to Marconi and Lakatos (2003), this is a comprehensive review of the main studies already carried out, recognized for its importance in providing current and relevant data on the subject. In addition, documentary research was used, which according to Gil (2002) is characterized by the collection of data exclusively from documents, whether

written or not, which are considered primary sources. This collection can take place at either the time the fact or phenomenon occurs or afterwards.

For analysis purposes, a meatpacking plant located in the southeastern region of the state of Mato Grosso do Sul was chosen. Data collection came from a primary source, carried out between January 2023 and June 2024. The data was collected directly from the meatpacker's integrated business management system (ERP), which provided detailed information on maintenance practices and associated resources. Monthly reports were extracted which included data on corrective and preventive maintenance, as well as financial and operational information. Specifically, data was collected on the financial resources used for maintenance, the number of interventions carried out each month and the plant's productive efficiency, measured in terms of downtime. Tabulation was carried out exclusively in Excel, which was used both to organize the information and to generate graphs. By analyzing the data collected, the aim is to provide a detailed overview of maintenance practices, identifying patterns and trends in costs.

4. RESEARCH

The object of the research is a beef slaughterhouse, which has been established in the interior of the state of Mato Grosso do Sul for 12 years. The company specializes in processing various types of meat and in manufacturing food products with additional value and practicality, with the aim of serving the national and international markets. At the time of the survey (July 2024), it had 780 employees, 28 of whom were in the maintenance area.

In the meatpacking plant analyzed, the maintenance sector plays an essential role, in charge of carrying out repairs and preserving both the equipment and the facilities. Activities are scheduled through the ERP system a week in advance, prioritizing preventive maintenance and then corrective maintenance. Any maintenance is only carried out by means of a work order. Work orders are distributed to the maintenance staff according to the type of activity to be carried out, whether electrical, mechanical or civil. Once they have been carried out, employees must finalize the work order in the system in order to generate a history, allowing monitoring, planning for the correct allocation of resources, as well as for use in internal and external audits.

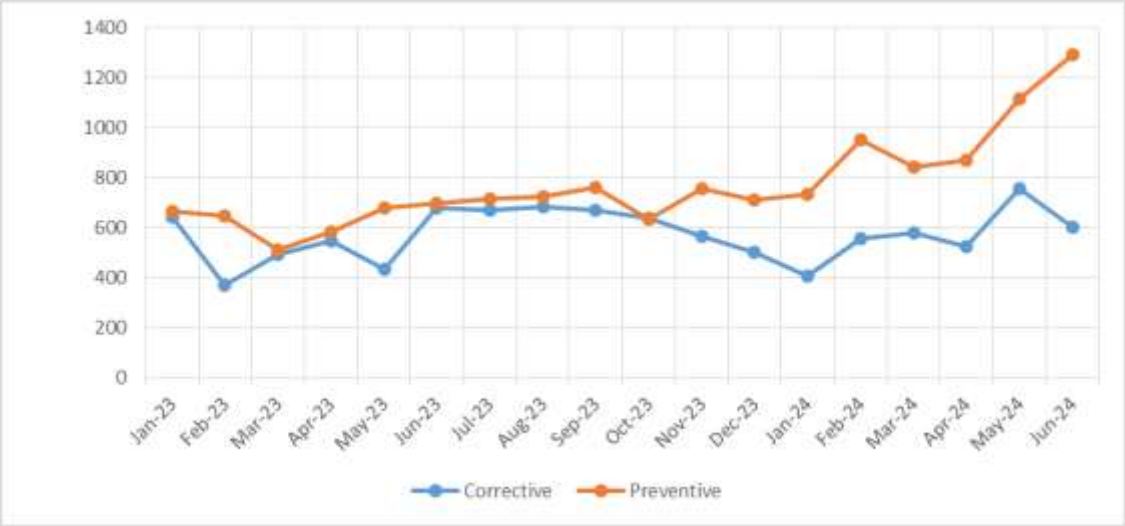
Therefore, the effective fulfillment of work orders is fundamental to obtaining accurate data and improving indicators, which in turn drives decision-making and the implementation of strategies for the continuous improvement of industrial operations.

4.1 Company maintenance data

Over the course of 18 months, all the costs and interventions carried out by the maintenance team were mapped, as well as the efficiency of the plant. The aim of this mapping was to create a detailed history, enabling a comprehensive analysis of the allocation of resources, the frequency of interventions and the efficiency of production processes.

Based on the records of the activities carried out, an overview of the interventions was drawn up, which made it possible to classify the maintenance carried out in the industry, both by type and by quantity, as shown in Graph 02.

Graph 02 - Interventions by maintenance type

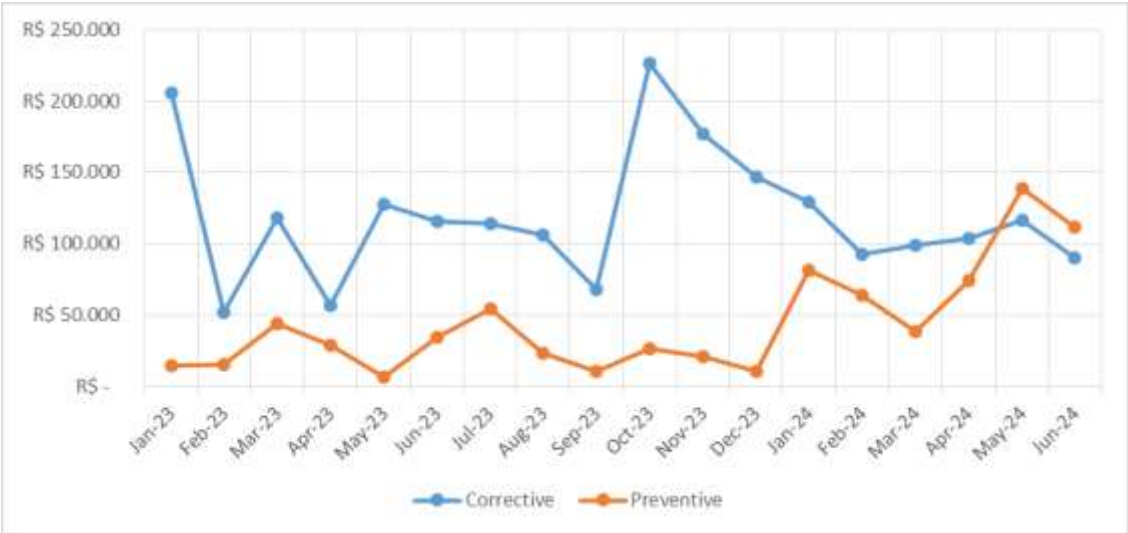


Source: Research data (2024)

Graph 02 shows that corrective work starts at 642 interventions in January 2023, varies over time, with some peaks, and falls. Preventive work began with 665 interventions in January 2023 and ended in June 2024 with 1,293 interventions.

Graph 03 shows a comparative analysis of the financial resources used for corrective and preventive actions.

Graph 03 - Financial resources by type of maintenance

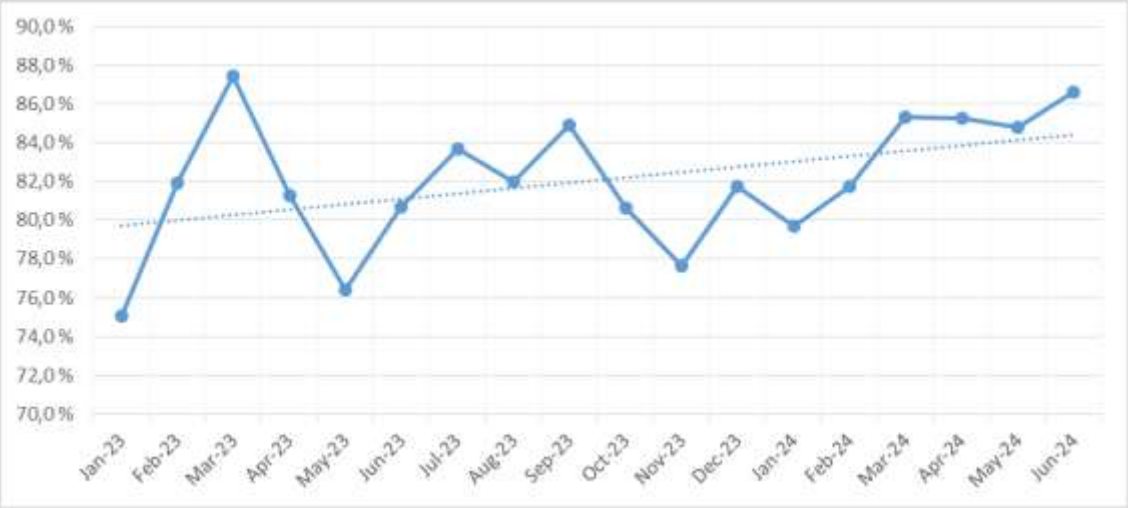


Source: Research data (2024)

It can be seen that the highest amount recorded is more than 226 thousand reais in the corrective category, in the period October 2023. In May 2024, the preventive category exceeded the corrective category by more than 139 thousand reais and remained higher the following month.

Graph 04 shows operational efficiency, which is a useful measure for assessing how the time available is being used for productive operations.

Graph 04 - Operating efficiency



Source: Research data (2024)

It can be seen that in January 2023 the efficiency recorded was 75.1% and 86.6% in July 2024, with some peaks during this period. It is worth noting that in March 2023, efficiency was recorded at 87.4%, due to the interruption of production on certain days of the month due to the unavailability of steers for purchase.

4.2 Research analysis

The study shows that as of the last quarter of 2023, the organization has made significant progress, evidenced by an increase in investments in preventive maintenance and a notable improvement in production efficiency
The data shows that, after October 2023, the resources spent on corrective maintenance decreased substantially This reduction can be attributed to the increase in preventive interventions, which began to show positive effects Although spending on preventive maintenance was still relatively low during this period, the amount of preventive interventions, even without involving large expenditures, played a crucial role in improving overall efficiency These interventions help to identify and mitigate problems before they become critical, contributing to a more stable and efficient operational performance
These increases are indicative of a continuous and gradual investment in preventive practices The improvement in production efficiency, which rose from 80.6% in October 2023 to 86.6% in June 2024, confirms that the intensification of preventive practices is generating positive results The improved efficiency shows that more effective management of resources and a greater focus on preventive maintenance have contributed to more efficient operational performance and a reduction in the need for corrective maintenance, which is in line with Figure 02 by Mirshawa & Olmedo, 1993, referenced in topic 2.3.
It can be said that the study achieved its initial objective, demonstrating how the increase in preventive maintenance practices positively influenced the organization's production efficiency. Analysis of the results confirms that the strategy implemented has brought significant operational improvements, reinforcing the importance of a preventive approach for effective resource management and greater stability in operations. Thus, the results obtained validate the success of the approach adopted and its compatibility with the objectives set.

5. CLOSING REMARKS

The aim of this study was to analyze the relationship between preventive maintenance costs and efficiency in industrial operations, focusing on a meatpacking plant as a case study. Throughout the research, it was possible to identify that implementing preventive maintenance practices contributes significantly to improving operational efficiency and reducing costs, as discussed in the theoretical framework. Adopting preventive practices not only minimizes unexpected downtime, but also optimizes the use of resources and extends the

useful life of equipment, which is essential for the continuity of operations and increased competitiveness in the industrial sector.

During the course of the study, it was essential to understand the evolution of maintenance practices in industrial operations. Initially focused on corrective maintenance, industries began to adopt preventive maintenance, a more effective and economical approach. This change was driven by the need to reduce the costs associated with unexpected failures, as well as to optimize the use of assets. In recent years, advances in monitoring technologies and data analysis have paved the way for new forms of maintenance, such as predictive maintenance, which allows greater control over the condition of equipment, anticipating failures and contributing to more efficient and sustainable operations.

The data collected was analyzed in order to identify trends and correlate investments in preventive maintenance with gains in operational efficiency. The results obtained confirm what is pointed out in the literature, that is, that investment in preventive maintenance is directly associated with increased efficiency in operations. From the analysis of the meatpacking plant's data, it was possible to see that, over the period studied, unplanned downtime was significantly reduced with the implementation of preventive routines. This reflected positively on improved productivity and lower repair costs, which reinforces the importance of preventive maintenance in the industrial context.

However, the research also had some limitations. One is the lack of comparisons with other companies, both in the same sector and in other industries, which could provide a broader view of the impact of this approach in different contexts. Another limitation is that, as this is an academic study, some variables have not been explored in depth, which leaves room for future research to investigate these aspects in more detail.

That said, for future research, we recommend exploring the topic in other industries and for a longer period, with the aim of validating the results in different contexts and scenarios. In addition, it would be important to further study the integration of predictive maintenance technologies, highlighting their advantages over traditional preventive maintenance. In this sense, a detailed analysis of the financial gains from the use of preventive maintenance is also suggested, considering not only the reduction in emergency repair costs, but also the benefits related to increasing the useful life of assets and improving operational efficiency. Such studies could contribute significantly to the evolution of maintenance practices in the industrial environment.

As a result, this study not only achieves the proposed objective, but also provides a starting point for other researchers to further investigate the relevance of preventive maintenance in various industrial contexts.

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