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Implementation Of Maintenance Indicators In The Grinding Sector Of A Chemical Industry: A Case Study

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Abstract:
Background: *In the current industrial scenario, companies aim to produce more and more using the smallest possible amount of resources. In this context, maintenance is a key function to ensure the highest possible efficiency of the factory.*
Materials and Methods: *The present work aimed to implement maintenance indicators in the grinding department of a chemical industry in the paint sector. Regarding the problem approach, this work was conducted through a qualitative and quantitative analysis. In terms of objectives, it is an exploratory research using the procedures of a case study, employing techniques of research based on documentary data.*
Results: *As results, the best approach for obtaining the indicators was identified. This method utilized tools that the company already possessed, revealing a series of improvements that can be implemented in the department through the introduction of these indicators.*
Conclusion: *Indicators are an essential tool to aid decision-making in various areas. In the maintenance sector, they can be used to assess which equipment requires more attention, enhance maintenance plans, and monitor the performance of production assets.*
Key Word*: Industrial maintenance. Indicators. MTBF. MTTR. Availability. Chemical Industry.*

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I. Introduction

Maintenance, as per Viana (2014), is a term derived from the Latin "manus tenere," meaning to maintain what one has. It has been a part of human life since the moment production tools began to be used. Its emergence as a function in the productive organism occurred in the 16th century with the arrival of the first mechanical looms. At that time, the machinery manufacturer trained the workers to operate and maintain the equipment, assuming the roles of operators and maintainers, as there was no specific maintenance team.

According to Viana (2014), the first techniques for service planning appeared around 1900. However, it was during World War II that maintenance established itself as a necessity, leading to significant developments in organizational techniques, planning, control, and decision-making.

With the evolution of equipment and the modernization of factories, maintenance became more complex. Organizations began to see this sector as a decisive factor for production efficiency, company development, and the economy (RAMOS, 2012). Therefore, having resources available to increase productivity and meet market demands is of utmost importance.

According to Santos (2018), with the rise of computers and sophisticated measurement and protection instruments, maintenance engineering split into two teams: chronic incident studies and Maintenance Planning and Control (PCM). PCM plays a strategic role in production by recording and analyzing maintenance service information, supporting production, operation, and maintenance managers.

The Brazilian Standard (NBR) 5462/94 defines maintenance as the combination of technical and administrative actions aimed at maintaining or restoring an item to a state in which it can perform the required function (ABNT, 1994). Similarly, Almeida (2018) states that the purpose of maintenance is to prevent losses due to unforeseen machine downtime, delivery delays, and more serious accidents involving machinery and vehicles. In general, maintenance includes all necessary procedures to keep machinery, equipment, and facilities operational.

Within the maintenance function, there are different forms of intervention. According to NBR 5462/94, there are three types of maintenance: corrective maintenance, preventive maintenance, and predictive maintenance. However, more recently, authors like Almeida (2015) highlight that just as machinery, tools, materials, and technology evolved with Mechanization, Industrialization, and Automation, maintenance has also evolved, both in terms of procedures and management, giving rise to maintenance types that address each industrial need. In addition to the types mentioned above, Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM) are included as forms of maintenance.

Regarding corrective maintenance, it is performed after a breakdown to restore equipment to a functional state (ABNT, 1994). This type involves replacing worn parts or components, causing downtime due to failures or breakdowns. Thus, significant effort is wasted on corrective actions (BRANCO FILHO, 2006).

Kardec and Nascif (2009) distinguish unplanned corrective maintenance, characterized by fixing a failure that has already occurred with no time for planning, potentially leading to higher costs and unexpected machine downtime. Planned corrective maintenance occurs when a performance decrease is known, but the decision is made to continue operating until failure or repair at the time of failure.

Preventive maintenance, on the other hand, is planned and controlled. It occurs at predetermined dates and aims to maintain equipment in proper working conditions, preventing unforeseen downtime (ALMEIDA, 2015). According to Xenos (2004), this maintenance method involves systematic steps such as inspections, overhauls, and primarily, component replacements.

Predictive maintenance aims to demonstrate actual machine operating conditions, considering data indicating wear. This methodology increases the interval between corrective and preventive maintenance, leading to higher operational availability (CYRINO, 2015).

Additionally, Total Productive Maintenance (TPM) emerged after World War II, when companies like Toyota developed administrative tools to reorganize their infrastructure and generate jobs. TPM encompasses both preventive and predictive maintenance, involving operators in machine monitoring and simple maintenance tasks (ALMEIDA, 2015).

Finally, Reliability-Centered Maintenance (RCM) can be defined as a program that combines various engineering techniques to ensure the continued functioning of industrial plant equipment as specified. Due to its rational and systematic approach, RCM programs are recognized as the most efficient way to address maintenance issues (FOGLIATO, 2009).

Given the importance and complexity of the maintenance sector in production, maintenance management involves administering the sector, organizing human and material resources, inputs, and strategic planning necessary to keep machinery, equipment, and facilities in good working order (ALMEIDA, 2018). According to Slack et al. (2010), maintenance management involves actions taken in both technical management and company relationships. It is implemented through routine service activities and improvements.

A maintenance management system, according to Facchini and Sellitto (2014), encompasses a set of strategically developed and integrated tasks to guide the team's actions, addressing the root causes of problems and anticipating breakdowns. The goal is to satisfy stakeholders through optimal service provision.

In the industrial landscape, where companies strive to produce more while using fewer resources to remain competitive, Key Performance Indicators (KPIs) have been developed to assist management in decision-making and process improvement. In performance monitoring, indicators are the most critical element, as they gauge company results for comparison with goals and assess deviations and corresponding performance levels (CALDEIRA, 2012).

As per Caldeira (2012), implementing indicators requires checking certain characteristics. For instance, it's essential to determine if the indicator's outcome is useful. It's important to assess whether the effort required to calculate the result is acceptable; in other words, the cost of obtaining the information should not exceed the value it provides. Proper and swift interpretation of results is crucial for decision-making, and linking targets to these indicators is also advantageous. This allows for assessing how far actual achievements are from ideal values.

In the case under study, several key indicators will be addressed to evaluate maintenance performance. These include Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and inherent availability. The following will explain the purpose of each indicator and provide the equation for calculation.

When considering MTBF, it is an indicator that reflects the time between the end of one intervention and the start of the next repair (MARTINS, 2012). The calculation involves analyzing the total hours of operation divided by the number of breakdowns within the same period, usually assessed monthly. For the analysis of this indicator, observing an increasing value indicates better equipment performance, requiring fewer maintenance interventions, or that maintenance is occurring at longer intervals.

When analyzing MTTR, it reflects the average time it takes to repair equipment. In this case, a lower resulting value indicates better maintenance team performance. Bezerra et al. (2019) mention several benefits of using MTTR. These include the ability to analyze which processes are more critical, which team has a higher service demand, allowing for personnel reallocation to better address these demands. MTTR also helps in observing occurrences and types of failures, aiding in the development of a predictive maintenance plan. Furthermore, it allows for estimating the average downtime of equipment for future corrective maintenance.

These indicators, MTBF and MTTR, are vital tools in assessing the efficiency and effectiveness of a maintenance team's activities. By monitoring these metrics, companies can optimize their maintenance strategies, reduce downtime, and enhance overall operational efficiency.

Furthermore, according to Bezerra et al. (2019), calculating inherent availability is crucial, as it assists the maintenance planning and control department in devising strategies to prioritize maintenance activities for specific equipment. Inherent availability calculation considers only the time equipment is stopped for corrective maintenance, not factoring in preventive maintenance downtime or other factors. This indicator is defined as the probability that a particular piece of equipment will be available when needed.

Inherent availability is a significant metric for understanding the reliability of equipment and how well it supports operational needs. By focusing on this metric, maintenance teams can allocate resources effectively and ensure that critical equipment is available when required, minimizing disruptions and enhancing overall productivity.

In this study, the indicators were applied to support decision-making in the maintenance sector of a chemical industry, specifically in the dispersion department, focusing on grinding equipment as part of a pilot project. The term "chemical industry" refers to the manufacturing of chemical products. In Brazil, there are two definitions for chemical products, one defined by IBGE (Brazilian Institute of Geography and Statistics) in partnership with Abiquim (Brazilian Chemical Industry Association), and the other by MERCOSUR (Southern Common Market) among member countries. The studied industry falls under the same product category in both definitions: the manufacturing of paints, varnishes, enamels, lacquers, and related products.

Similarly, the grinding process is utilized in various industries such as ceramics, crushing, pharmaceuticals, and food processing. According to Bernardo and Oliveira (2018), grinding is crucial in the paint industry for proper incorporation of pigments into paint compositions. This process significantly impacts the final quality of the painting system, and mills are commonly used for this purpose.

The industry under study has eleven mills in its production line, with five constructed horizontally and six vertically. The equipment follows a numerical sequence for tracking, where the first three letters represent the asset family followed by the numerical sequence (e.g., MOI-0001 to MOI-00111 were used in this study).

The primary goal of this work was to implement maintenance indicators in the grinding department of a paint industry located in the southernmost part of Santa Catarina, Brazil. To achieve these objectives, the study involved understanding the maintenance call management process, identifying suitable indicators for the sector and equipment, determining the best method for collecting necessary data, and subsequently analyzing the implemented indicators.

This study holds importance for the industry as it assists in precise control over the equipment within the factory, facilitating decisions about equipment needing shorter intervals between preventive maintenance. Furthermore, by implementing indicators, performance can be compared with other studies to gauge whether the sector's performance aligns with other organizations.

Maintenance management is pivotal within organizations as it ensures facility functionality and assists in achieving high levels of productivity to remain competitive (GONÇALVES; DIAS; MACHADO, 2015). With the necessary information, planning becomes more effective in meeting production demands and scheduling necessary interventions in the factory.

From an academic perspective, this study offers an opportunity to apply skills acquired during education, employing tools that aid decision-making. Moreover, it can lead to environmental improvements by creating a more reliable factory, reducing the likelihood of accidents, breakdowns, leaks, and defects that might harm the environment.

II. Methodology

Methodology is the combination of systematic and rational activities that allows achieving the objective of producing valid and true knowledge with greater reliability and economy, making it possible to detect errors and assisting in the decisions of the scientist (LAKATOS, 2021).

According to Gil (2022), research can be classified based on objectives or purposes. There is exploratory research, which aims to provide greater familiarity with the problem, making it more explicit. Research can also be descriptive, aiming to study the characteristics of a specific population or phenomenon. Additionally, there is explanatory research, where the purpose is to identify conditions that determine or assist in the occurrence of phenomena.

A case study is a detailed description and analysis of a case that presents particular characteristics. This type of study can provide a wealth of data and information contributing to the field of knowledge in which it is applied.

Regarding the problem approach, this work used both qualitative and quantitative methods. In terms of objectives, it falls under exploratory research. As for the procedures, it involves a case study using techniques of research based on documentary data. The study was conducted in a chemical industry located in the southernmost part of Santa Catarina.

Regarding the methodology used for implementing the indicators, with the aim of finding the most efficient implementation method, two distinct methods were tested, referred to as Method 01 and Method 02. Both methods aimed to utilize resources available within the company, thereby avoiding the need for investments in tools and software.

For data collection, the Maintenance Work Order System was utilized, where maintenance requests for the mill family were tracked on a daily basis. The data collection occurred between December 2022 and April 2023. The required data for obtaining the results included the opening time of the request, the start time of the service, the completion time, and the number of maintenance requests per equipment.

In December, Method 01 was employed. This method involved using Microsoft Excel for calculating the indicators. Automation was achieved using cell colors, where each mill was assigned a specific color. Table 01 illustrates the arrangement of data used for calculations for the mentioned month.

Table 1: Data obtained in December 2022

Ticket	Equipament	Opening Date	Opening Time	Service Start	Service End	Hours in Service
18398	**MOI-0009**	01/12/2022	07:35	07:40	08:20	**00:45:00**
18448	**MOI-0010**	02/12/2022	18:19	18:20	20:00	**01:41:00**
18455	**MOI-0004**	03/12/2022	03:32	07:30	10:00	**06:28:00**
18459	**MOI-0007**	05/12/2022	06:53	08:00	08:50	**01:57:00**
18490	**MOI-0004**	06/12/2022	06:15	06:20	07:31	**01:16:00**
18498	**MOI-0004**	06/12/2022	09:58	10:00	15:10	**05:12:00**
18590	**MOI-0009**	09/12/2022	18:03	18:05	18:20	**00:17:00**
18607	**MOI-0008**	12/12/2022	05:32	05:50	06:40	**01:08:00**
18616	**MOI-0010**	12/12/2022	07:40	07:40	08:00	**00:20:00**
18702	**MOI-0010**	14/12/2022	16:51	16:51	17:15	**00:24:00**
18703	**MOI-0010**	14/12/2022	16:51	17:20	18:00	**01:09:00**
18721	**MOI-0008**	15/12/2022	14:21	14:30	14:52	**00:31:00**
18722	**MOI-0010**	15/12/2022	14:22	14:50	15:14	**00:52:00**
18728	**MOI-0010**	15/12/2022	18:26	18:35	19:00	**00:34:00**
18775	**MOI-0003**	18/12/2022	06:06	07:55	08:25	**02:19:00**
18776	**MOI-0001**	18/12/2022	08:01	08:40	09:10	**01:09:00**
18790	**MOI-0004**	19/12/2022	09:39	09:40	11:05	**01:26:00**
18834	**MOI-0010**	21/12/2022	05:37	05:40	06:00	**00:23:00**
18844	**MOI-0010**	21/12/2022	10:04	10:05	10:25	**00:21:00**
18896	**MOI-0001**	23/12/2022	12:06	12:10	12:25	**00:19:00**

Source: Authors, 2023

Still during the month of December 2022, upon commencing data collection, it became evident that using Microsoft Excel would result in a high energy expenditure to obtain the indicators, as it would consistently require manual input into the spreadsheet. Considering that the present work aims to bring improvements that the company can utilize after the study's completion, alternative methods for data collection were sought.

As a result, research began on the Enterprise Resource Planning (ERP) system utilized by the company, where it was found that TOTVS is a widely used system for maintenance management. Therefore, starting from January, Method 02 was employed. After a maintenance service request was opened in the Maintenance Work Order System, the requests were manually replicated in the TOTVS system. This was done to assess the feasibility of migrating the maintenance system to the company's ERP and consolidating all information in a single platform.

For this reason, only the data obtained between January and April 2023 were considered for presenting the results in this study. The data from December 2022 was used for testing purposes to validate the best method for obtaining the indicators.

III. Results

As demonstrated in the data collection procedures, the month of December 2022 was used to determine the best way to obtain and analyze information in order to seek lasting improvements for the industry under study. For this reason, during this period, the sector's working tool, Microsoft Excel, was used to store the data. However, it was recognized that this manual method would become impractical for implementing across all asset families in the company, as the average number of opened service requests per month from December 2022 to April 2023 was 675.

Given the described situation, Table 02 illustrates the indicators calculated per equipment for the month of December using Method 01. To obtain the results, the formulas for MTBF, MTTR, and availability described in the introduction of this work were employed. However, as Method 02 was utilized for obtaining indicators in the subsequent periods, the data from Table 02 was not used for analyzing the cumulative data of this study.

Table 2: Maintenance Indicators for December (Method 01)

Equipament	DECEMBER					
	Hours Worked	Hours in Maintenance	Number of Service Requests	MTBF	MTTR	Availability
MOI-0001	408:00:00	1:28:00	2	203:16:00	0:44:00	100%
MOI-0002	408:00:00	0:00:00	0	408:00:00	0:00:00	100%
MOI-0003	408:00:00	2:19:00	2	202:50:30	1:09:30	99%
MOI-0004	408:00:00	14:22:00	4	98:24:30	3:35:30	96%
MOI-0005	408:00:00	0:00:00	0	408:00:00	0:00:00	100%
MOI-0006	408:00:00	0:00:00	0	408:00:00	0:00:00	100%
MOI-0007	408:00:00	1:57:00	1	406:03:00	1:57:00	100%
MOI-0008	408:00:00	1:39:00	2	203:10:30	0:49:30	100%
MOI-0009	408:00:00	1:02:00	2	203:29:00	0:31:00	100%
MOI-0010	408:00:00	5:44:00	8	50:17:00	0:43:00	99%
MOI-0011	408:00:00	0:00:00	0	408:00:00	0:00:00	100%

Source: Authors, 2023

With the search for a new method of implementing indicators, it was realized that migrating the management tool to the ERP used by the company would not only generate the selected indicators for implementation but also offer a range of benefits for the maintenance sector. Among the identified advantages are the consolidation of the system used for preventive and corrective maintenance, automatic storage of the maintenance history for each equipment through the opening and closing of work orders, and the ability to measure maintenance costs through labor and replacement parts expenses.

In addition to the aforementioned gains related to asset management, the utilization of this software can bring improvements to service and labor control. In the previous working method, technicians were responsible for dividing the tasks, while in the proposed approach, task distribution would fall under the responsibility of the PCM analyst and maintenance supervisor. They would allocate tasks based on each technician's expertise and specialization to ensure that the work is carried out in the most efficient manner.

Another aspect observed regarding the ERP system is its advanced development, allowing the utilization of more advanced technologies. For instance, it can be used on mobile devices through an application. These features assist the field team in visual management of tasks, expedite the recording of activities performed, and include a timer in the application for more accurate tracking of time spent on each task. This enhances the information within the service requests and increases the reliability of the indicators.

Table 03 presents the indicators for the months of January to April 2023, categorized by equipment according to their assigned codes.

Table 3: Indicators calculated for the period from January to April 2023

Equipament	**January**			**February**			**March**			**April**		
	MTBF	**MTTR**	**Disp.**	**MTBF**	**MTTR**	**Disp.**	**MTBF**	**MTTR**	**Disp.**	**MTBF**	**MTTR**	**Disp.**
MOI-0001	105:00	00:36	99,4%	201:00	00:36	99,7%	311:24	00:36	99,8%	339:28	00:32	100%
MOI-0002	528:00	00:00	100,0%	1006:02	01:57	99,8%	1558:02	00:00	99,9%	508:59	01:02	100%
MOI-0003	83:19	05:16	94,7%	81:11	03:07	96,6%	101:24	02:50	97,5%	117:34	02:39	98%
MOI-0004	260:05	03:55	98,5%	199:29	02:07	99,0%	153:12	25:27	88,4%	142:48	17:49	91%
MOI-0005	131:10	00:50	99,4%	251:10	00:50	99,7%	389:10	00:50	99,8%	509:11	00:50	100%
MOI-0006	528:00	00:00	100,0%	1003:10	04:49	99,4%	517:50	02:09	99,5%	508:16	01:44	100%
MOI-0007	129:18	02:42	98,0%	166:04	01:55	98,9%	193:26	01:34	99,1%	225:13	01:27	99%

MOI-0008	175:48	00:12	99,9%	201:06	00:30	99,8%	193:21	01:39	99,2%	183:53	01:35	99%
MOI-0009	96:37	18:35	91,5%	79:58	08:05	95,2%	93:35	06:58	96,0%	116:08	06:54	97%
MOI-0010	51:26	01:22	97,4%	74:40	05:07	95,6%	95:01	04:19	97,0%	103:56	13:42	91%
MOI-0011	528:00	00:00	100,0%	1006:48	01:11	99,9%	1558:48	00:00	99,9%	679:09	00:51	100%

Source: Authors, 2023

Upon observing the results for the period, it can be noted that due to the current maintenance method being predominantly unscheduled corrective maintenance, it is not possible to predict when each asset will require a repair, making planning difficult and potentially leading to high costs, in line with the findings of Kardec and Nascif (2009). Another observation is that, despite having a high number of failures, most of them are repairs of low complexity, such as pneumatic components like flow control valves and pneumatic connections. These repairs can restore the equipment to operation in short periods of time, which is why the mean time to repair is short and equipment availability is high, except in more complex cases like changing the mill's liner and seal, as occurred with MOI-0004 in March and MOI-0010 in April, where the asset indicators were influenced.

It was also noted that operational conditions have an impact on the equipment's lifespan, as the equipment that is more heavily utilized in the production line had a shorter mean time between failures compared to assets working in product lines with lower demand, such as MOI-0002, MOI-0006, and MOI-0011, which experienced fewer failures during the study period. This observation showed that the frequency of maintenance is lower for equipment processing various types of products and operating under more severe conditions.

Since the scope of the study was limited to identifying the best method for implementing indicators to be used by the company, no specific goals were defined for these indicators beyond the stipulated period. However, it was suggested that the maintenance department consider setting goals for each metric to track the progress of both the department and the equipment over time. Thus, implementing maintenance indicators enables the department to strategically organize continuous improvement actions for the company, in line with the findings of MUCHIRI et al. (2011), which conclude that indicators assist maintenance managers in strategically organizing resources and teams in specific production sectors that have the potential to influence factory performance.

IV. Final considerations

In this study, it was possible to conclude that the use of indicators will assist the company in monitoring the state of the factory and determining where to focus efforts for improvements and asset updates. In the sector used as a pilot cell, it was observed that despite having a high number of service requests, it maintains high availability due to the low complexity of most of the interventions. However, with the use of the recommended software, it will be possible to track the history of key component replacements in equipment, as seen with MOI-0004 and MOI-0010. This will enable proactive maintenance before equipment failures occur, based on historical data regarding the lifespan of these components.

Furthermore, such metrics are essential for future implementation of preventive maintenance, as it requires a database of equipment with their failure frequencies to develop maintenance plans that act before assets experience failures.

Thus, it can be concluded that improvements were successfully introduced to assist the company's maintenance sector through software enhancements, ensuring efficiency and reliability of services by utilizing information. The goal was to identify the best way to obtain indicators with minimal energy expenditure. When these metrics are applied to the remaining assets, it will happen seamlessly, without requiring administrative staff's extra efforts.

Considering the significance of maintenance management as a means to enhance company efficiency and competitiveness in the market, the importance of studies that enhance management tools in this sector is emphasized. For instance, comparing maintenance indicators in companies that rely solely on corrective maintenance with those applying preventive and predictive maintenance could demonstrate the potential gains that modern maintenance techniques can bring to a company.

Another opportunity for future work lies in measuring the cost of equipment downtime, allowing assessment of the production losses incurred due to maintenance activities.

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