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Preventive Maintenance Analysis Based on Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR)

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ABSTRACT

A manufacturing company's ability to meet its goals depends heavily on the smooth operation of its production process. Hence, it is crucial to have optimal maintenance to run the business smoothly. This study aims to identify the root cause of the malfunction in the soda and dolomite bucket elevators by analyzing the MTBF, MTTR, and a qualitative assessment through Failure Modes and Effects Analysis (FMEA). The study also found that actual preventive maintenance (PM) action was usually 3 days ahead of the scheduled PM (i.e., 30-day cycle). This issue indicates that the company may experience unexpected failures and other problems associated with the PM action. The FMEA results revealed that suboptimal maintenance by company staff and other root causes potentially affect the PM enactments indicated by the high Risk Priority Number (RPN) score. Finally, several recommendations are proposed to cope with the issues according to the findings of this study.

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1. *INTRODUCTION*

Regular maintenance is essential for repairing damages and improving machine performance. This is especially important in industries that require high-quality output and constantly evolving production processes. A malfunctioning machine can cause production processes to come to a standstill. Therefore, maintenance on machines before any damage occurs is crucial in reducing repair costs and maintaining product quality [1]. *Vernor's opinion* [2] *In his book Maintenance Planning and Control Handbook, Maintenance is defined as a combination of all technical, administrative, and managerial actions throughout the life cycle of an item, aimed at maintaining or restoring it to a condition where it can fulfill its designated function. Maintenance is a crucial set of care and repair activities that ensure the consistent reliability and availability of machines or production equipment. This enables them to produce high-quality products efficiently and cost-effectively and hence, increase customers' satisfaction by protecting them from non-conformity product. Model failure process of each type of components, which considers a bidirectional (or mutual) failure interaction between the C and NC components. Hence, each component has two types of failures -i.e., natural failure and induced failure* [3][4]. *As Sudarno* [5] *explains, this process is essential to the success of any production operation. Maintenance in the Industry 4.0 environment is essential for enhancing maintenance operation capabilities and achieving optimal efficiency* [6]. *It is crucial to understand that maintenance can be classified into two types: Preventive and Corrective. Preventive Maintenance is a proactive approach that aims to prevent unexpected downtime. It significantly prolongs equipment lifespan, enhances performance and efficiency, and ultimately reduces overall maintenance expenses. It is imperative to prioritize Preventive Maintenance to ensure minimal disruptions and keep your equipment running smoothly* [7]. *Preventive Maintenance is conducted by performing scheduled maintenance on equipment, such as cleaning, lubrication, replacement of worn components, and equipment adjustments* [8]. *Preventive maintenance keeps equipment in excellent condition to prevent downtime or damage. It's done based on time* *intervals or usage* [9]. *Maintaining optimal equipment and system conditions is crucial to avoiding substantial damage and downtime* [9]. *Corrective Maintenance is the essential process of restoring equipment to its normal functioning state after experiencing any kind of failure or damage* [10]. *Corrective maintenance (CM) needs to be implemented on a machine that has experienced failure to restore its operational functionality* [11]. *Understanding the management of machine performance maintenance is crucial, and it comprises three vital components: Reliability, Maintainability, and overall machine Availability. These components are measured by Mean Time Between Failure (MTBF), Mean Time to Repair (MTTR), and Availability-focused maintenance, respectively. Conducting Availability-focused maintenance is imperative in determining the capability of physical assets to perform as intended* [12].

PT. MI *Maintenance plays a crucial role in achieving the Quality Objective target (Zero Breakdown) within the Engineering Department to support the production target of* 91% *efficiency. Reliability is the probability of an item performing a predetermined function under specific operational and environmental conditions for a specified period* [13]. *Based on the company's trouble report data, it is indicated that there are three pieces of equipment with the highest damage frequency. These are the soda and dolomite bucket elevator equipment with a damage frequency of* 37%, *the* 16 x 5 *feet power screen equipment with a damage frequency of* 33%, *and the silica sand bucket elevator equipment with a damage frequency of* 30%. *This study will focus on the soda and dolomite bucket elevator equipment* 1032 *due to its highest damage count in* 2022. *Furthermore, field observations reveal that the maintenance cost for this equipment has been consistently increasing from* 2019 *to* 2022. *This research will discuss the Bucket Elevator Soda & Dolomite* 1032 *equipment as it had the highest damage rate in* 2022. *Furthermore, the maintenance cost of this equipment has been consistently increasing from* 2019 *to* 2022. *To address this issue, we need to identify the root cause of the problem and find its solution using the Mean Time Between Failure* (MTBF) *and Mean Time to Repair (MTTR)* calculation *methods. The purpose of this investigation is to pinpoint the underlying factors that contributed to the malfunction of the soda and dolomite bucket elevator. This will be accomplished by examining the Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR), as well as performing a qualitative assessment through the Failure Mode Effects Analysis (FMEA) method.*

According to Prabhakar, et al [14] *MTBF is a measurement of the average time between failures in a system or component. This can be calculated by dividing the* Sum operation *time by the number of failures. Meanwhile, Mean Time to Repair* measures *the average time it takes to repair a system or component* after a failure. *MTTR can be calculated by dividing the Sum of downtime by the number of recovery or repair events* [15]. *FMEA (Failure Mode and Effects Analysis) is a* systematic *method for* identifying, *analyzing, and reducing the risk of failure in* a process, product, or system. *This method involves identifying potential failures, assessing severity, probability of occurrence, and failure detection capabilities. The goal is to identify preventive or corrective actions that can reduce the risk of failure and improve the quality and reliability of the product or process* [16]. *A Risk Priority Number (RPN) is a* number used in FMEA *to measure the level of risk of failure. RPN is obtained by multiplying three critical factors in FMEA analysis, namely Severity (severity of failure impact), Occurrence (frequency of failure), and Detection (ability to detect failures before reaching customers). The higher the RPN value, the higher the level of risk associated with such failures* [17].

The previous research conducted by Maciej Kuboń, et al [18] *Indicates that the parameters of MTBF (Mean Time Between Failures) and MTTR (Mean Time to Repair) have a significant influence on the reliability and productivity of technical systems. A higher MTBF value, indicating longer periods between failures, leads to increased system reliability and productivity. Conversely, a shorter MTTR value, indicating faster repair times, also contributes to improved system performance. Based on the findings of previous research Oki Sunardi, et al* [19] *discuss the effectiveness of machines in the manufacturing industry and emphasize the importance of maintenance in improving productivity and reducing costs. The study uses the Total Productive Maintenance approach and calculates the Mean Time Between Failure and Mean Time to Repair. The findings suggest implementing preventive maintenance and improvements to increase machine life. The findings of previous research Indicate that the critical components of the* 1000*-ton hydraulic press machine are the V-Packing and Contactor. V-Packing experiences 8 failures at a rate of 32% of the total failures, while the Contactor experiences* 6 *failures, accounting for 24% of the total failures. Overall, this study provides a step-by-step approach to determine the optimal maintenance actions for the* 1000*-ton hydraulic press machine based on the RCM method. Critical components are identified, and reliability analysis is conducted to calculate the values of MTBF (Mean Time Between Failures) and MTTR (Mean Time to Repair)* [20]. *The findings of previous research the study analyze the current maintenance management condition and propose a change in the maintenance schedule based on* the *Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) methods. The research found that the maintenance schedule for the centrifugal compressor machines should be changed from every* 3 *months to every* 2 *months* [21]. *A previous study examined performance maintenance* *by analyzing Mean Time Between Failure (MTBF), Mean Time To Repair (MTTR), and machine availability data from May 2019 to April 2020. The study aimed to assess the maintenance system's condition and determine areas for improvement. The results showed that the machine's reliability is unstable, the MTTR graph is stable, indicating good maintenance operator skills, and machine availability needs improvement [22]. The study also calculated the machine's effectiveness using MTBF and MTTR and illustrated machine repair activities using Maintenance Value Stream Mapping (MVSM). Based on the findings, the machine that frequently experiences breakdown is TM-10, mainly due to faulty parts, accounting for 49%. The repair efficiency value increased from 27.93% to 41.67% after repair [23]. Previous research findings [22] showed that there were two critical components with an indication of the increasing failure rate, during wear-out (β value> 1), which are namely cylinder press and EPV with an MTBF value of 89 days for cylinder presses and 231 days for EPV. The results of this study propose updating the curing machine PM schedule [24]. Based on the observational data, the MTBF has reached 3458 minutes, and the MTTR has reached Â minutes. Meanwhile, the Availability Performance (AP) only reaches 95.1%, which hampers the Extruder type 150's optimal operation and disrupts the production process [25]. The study also calculated the MTBF and MTTR values of each machine and determined the maintenance item's significance by the MTBF value. After analyzing the root causes of the issues, several improvements have been made, demonstrating an increase in the maintenance period for the corrugator, flexo, and glue machines [26]. The study also performed quantitative analysis by calculating MTBF, MTTR, and determining reliability and failure rate. The results showed that the mill fan has the lowest reliability rate based on its Inherent Availability, standing at 79.92% [27]. The machine used must be guaranteed to operate at high performance, so periodic inspections must be carried out. In machine maintenance activities at PT. SNP is not based on damaged data as a reference, and in its implementation is still not programmed. In this study, a solution will be sought to overcome the problem of optimal machine scheduling by considering the cost of repairs and the number of repairmen. The historical data of engine failure will be used to calculate the Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) and model the engine maintenance so that it is expected to be able to reduce repair costs [28]. In previous research exciting results were obtained for Mean Time to Repair (MTTR) as follows: sand filter 0.48 hours, bag filter 0.68 hours, cartridge filter 1.22 hours. The Mean Time to Failure (MTTF) values were: sand filter 684 hours, bag filter 190.3 hours, cartridge filter 236.8 hours. Furthermore, the Mean Time Between Failure (MTBF) values were as follows: sand filter averaged 708 hours, bag filter averaged 214.8 hours, and cartridge filter averaged 260.8 hours per year. In addition to MTTR, MTTF, and Mean Time Between Failure (MTBF), other research findings include the reliability values for the filters: sand filter with a value of 0.178, bag filter with a value of 0.0053, and cartridge filter with a value of 0.00889 [29]. The recommendation for PT. XYZ is to implement the autonomous pillar and scheduled part replacement to solve issues at the factory, and to focus on critical work areas; i.e., dryer-cooler station, areas with the highest breakdown duration and mean time to repair (MTTR), and the lowest mean time between failures (MTBF) [30]. The analysis of the Dump Truck HD 1500-7 unit's maintenance performed from February to April 2022 revealed that the average MTBF value is 352.9 hours, the average MTTR value is 5.388 hours, and the average PA value is 96.38% [31].*

However, the research that combines the quantitative and qualitative approaches to analyze the actual predictive maintenance is still scarce. According to the above-mentioned research, prior studies utilized only either qualitative or quantitative approaches. Thus, in this research, a new approach to analyzing and identifying root causes is conducted from a managerial perspective by integrating quantitative approaches (i.e., MTBF and MTTR) with qualitative methods such as fishbone diagrams and Failure Mode and Effects Analysis (FMEA). In this study, a fishbone diagram is utilized to analyze potential root causes. Whilst, FMEA is generated to identify potential failures through the Risk Priority Number (RPN) obtained by this method, which allows the company to apply some preventive actions or improvements to reduce the risk of failure and enhance the quality and reliability of products or processes.

The following is the structure of this study. In the first section, the background and literature review have been explained by this study. Moreover, the second section will describe the research method used in this study study is a combination of quantitative (i.e., MTBF and MTTR) and qualitative descriptive (i.e., fishbone and FMEA) approach, which is assumed to be more comprehensive than the prior studies. Next, the third section will elucidate the findings and analysis, leading to the solutions derived from this research, and the final section will comprise the conclusion and suggestion.

2. *RESEARCH METHOD*

The research methodology used in this study is a combination of quantitative (i.e., MTBF and MTTR) and qualitative descriptive (i.e., fishbone and FMEA) approach, which is assumed to be more comprehensive than the prior studies. These approaches enables researchers to delve deeper and provide a comprehensive overview of the various aspects related to machine maintenance in the PT. MI during 2022. The data utilized in this study comprises secondary and primary data. Secondary data, which serves as the initial foundation of *the study, are obtained from daily maintenance reports and data recorded in the company's systems. Daily maintenance reports provide insight into various issues that arise during day-to-day operations. Data from the company's systems includes valuable historical records related to machine maintenance. Through the analysis of this secondary data, researchers can understand standard patterns and trends that may emerge in machine failures and track how maintenance management has evolved so far. However, this secondary data is only a starting point.*

To gain a deeper and contextual understanding primary data collection is carried out, researchers conducted interviews with key stakeholders, including 1 Superintendent, 1 Supervisor, and 3 Mechanical Staff from PT. MI. *This interview opens the door to gaining valuable insight into their experience in dealing with machine maintenance issues, existing policies and procedures, and any obstacles that may be encountered in the engine repair process. The data collected from these interviews includes essential information such as the most common types of machine breakdowns and factors causing engine failure. In addition, respondents also provided their perspectives on the lead times involved in the repair process and the associated maintenance costs.*

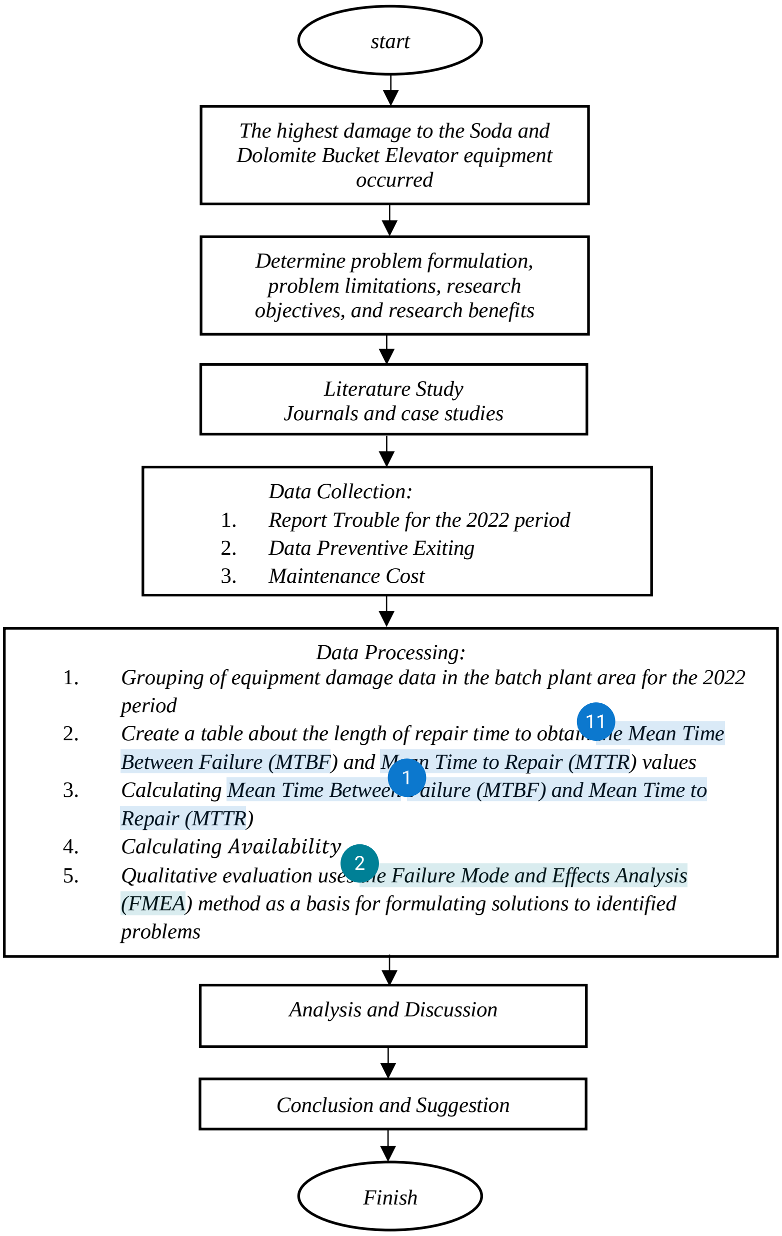

Figure 1. *Research process flow*

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After the required data has been gathered, the next step is to process the data according to the established method based on the characteristics of the problem. The aim is to categorize the damage data throughout the year 2022 *to identify the equipment that most frequently experiences malfunctions. Subsequently, calculations of Mean Time Between Failure (MTBF) and Mean Time to Repair (MTTR) are conducted as essential parameters for analyzing equipment performance. Next, an analysis is performed on the results of the MTBF and MTTR calculations. The next step involves qualitative evaluation using the Failure Mode and Effects Analysis (FMEA) method as a basis for formulating solutions to the identified issues. Following that, conclusions are drawn, and recommendations are provided based on the results of the analysis and discussion that have been conducted.*

Furthermore, data from both sources will be analyzed together to identify patterns, challenges, and potential improvements in machine maintenance management at PT. MI. *The findings of this study will provide a comprehensive picture of machine maintenance issues during* 2022 *and may form the basis for better recommendations for future machine maintenance management.*

3. *RESULTS AND ANALYSIS*

After data collection was carried out, three machines with the highest amount of damage were obtained as follows:

Table 1. *Highest Damage Frequency Data*

No	***Problem Type (Machine)***	***Frequency***	**%**	***Cumulative (%)***
1	*Preventive Bucket Elevator Soda and Dolomite* 1032	11	37%	37%
2	*Preventive power screen 16 x 5 feet*	10	33%	70%
3	*Preventive bucket elevator silica sand 1031*	9	30%	100%
	Sum	30	100%	

Furthermore, the calculation of MTTR and MTBF is carried out with the following equation.

$$MTBF = \frac{Total\ (Downtime - Up\ Time)}{Number\ of\ Failure} \quad (1)$$

$$MTTR = \frac{Total\ Maintenance\ Time}{Number\ of\ Repair} \quad (2)$$

MTTR is calculated from the length of repair time while MTBF is calculated from the last range of the engine repaired until the machine is damaged again.

Table 2. MTTR and MTBF Calculation Results

Equipment code	***Description***	***Action***	***Repair***		***MTTR***	***MTBF***
			Start	***Finish***		
100021151	*Found the Condition of the Bolt Bucket Has Begun to Break Down*	*Replace Bolt &; Nut Bucket elevator + Ring (30 Sets)*	21/01/2022 09:30	21/01/2022 10:30	60’	70770’
	Bowl Condition &; Bucket Bolts Damaged (Wear & Dent)	*Replace 400or225 Bucket Bowl (5pc) + Change Bolt &; Nut Bucket elevator + Ring (30 Sets)*	11/03/2022 14:00	11/03/2022 16:00	120’	73620’

Equipment code	*Description*	*Action*	*Repair*		*MTTR*	*MTBF*
			Start	*Finish*		
	Sensor or Blocked Bucket, Does Not Work Optimally (At the time of the stop, the motor is still operational so that the V. Belt slips and breaks	*Replace V. Belt Drive Spare New V. Belt Spa-2432 Rubber (4pc)*	01/05/2022 19:00	02/05/2022 21:00	120’	8520’
	Sensor or Blocked bucket, does not work optimally (at the time of the stop, the motor is still operational so that the V. Belt slips and breaks	*Replace V. Belt Drive Spare New V. Belt Spa-2432 Rubber (4pc)*	08/05/2022 19:00	08/05/2022 21:00	120’	67260’
	When P or S work was found, a condition was found that there was a material in the bucket casing	*Casing Patch with Glue Silicone (Building & Glazing) (2 Tubs)*	24/06/2022 14:00	25/06/2022 15:00	60’	27240’
	When P or S Work Requires Material Replacement	*Replace bucket bowl 400or225 (15pc) &; replace bolt and nut bucket elevator + ring (60 sets) & adjuster elevator belt*	14/07/2022 13:00	15/07/2022 15:00	120’	38820’
	When P or C Work Found &; Bucket Case Damper Condition There Is Material Leakage	*Repair Leaks in Damper Casing Bucket, Glue Silicone (Building &; Glazing) (2 Tube), Repair Motor Exs. Diwor S for spare bearings 6210 ZZ C3 (1 pc), bearing 6211 ZZ c3 (1 pc), and motor settings*	11/08/2022 14:00	12/08/2022 15:00	60’	50340’
	When P or C Work Required Regreasing Bearings	*Greasing With Car Grease Xhp 222 (0.100 Pie), Damper Lid Bucket Case with Glue Silicone (Building &;*	16/09/2022 14:00	17/09/2022 15:00	60’	38820’

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Equipment code	***Description***	***Action***	***Repair***		***MTTR***	***MTBF***
			Start	***Finish***		
		Glazing) (2 Tubs)				
	When P or C work is found, the condition of the bucket is already an indication of damage	*Replace 4pc Spare Exs Bucket Bowl. Repair Ws, Replace Bolt &; Nut Bucket elevator Ring (30 sets), and Glue Silicon (Building &; Glazing) (2 Tubs)*	14/10/2022 14:00	15/10/2022 15:00	60’	48900’
	When P or S Work Requires Material Replacement	*Replace Bolt &; Nut Bucket elevator + Ring (30 Sets), Replace Bucket Bowl 4 Pc Spare Exs. Repair*	18/11/2022 14:00	18/11/2022 15:00	60’	47460’
	When P or C Work Found &; Bucket Case Damper Condition There Is Material Leakage	*Repair Damper Casing Bucket Glue Silicone (Building&Glazing) (2 Tubs)*	21/12/2022 14:00	12/12/2022 15:00	60’	
Sum					**900’**	**471750’**
Average					**81,82’**	**47175’**
			1 *Day* = 1440 *Minutes*			32,76 *Days*
			32,76 *Days* ≈ 33 *Days*			

Over an entire year, a machine can operate continuously for 24 hours a day. This amounts to a Sum of 525,600 *minutes of operational time. By using this Sum of Operation Time, the machine's Availability can be accurately calculated.*

$$Availability = \frac{Operating\ Time}{Sum\ Operating\ Time} \times 100\% \quad (3)$$

$$Availability = \frac{471750-0}{525600} x\ 100\% = 89{,}75\% \approx 90\%.$$

Based on availability calculations, the soda and dolomite 1032 *elevator bucket equipment perform optimally with an availability rate of 89.75%, which is just slightly under the optimal standard of 90%. However, it poses a significant risk of damage without proper treatment. Therefore, it is imperative to schedule optimal maintenance to prevent frequent machine damage.*

Based on MTBF and MTTR calculations, the actual preventive maintenance (PM) schedule for the Soda and Dolomite 1032 *elevator bucket is every* 33 *days in a cycle. Whilst, the company's required PM schedule is conducted every* 30 *days. According to these data, the PM actions are often* 3 *days ahead of the required schedule in overall. This issue will produce sudden failure in the machine which leads to the corrective maintenance (CM) action and hence, produce a higher maintenance costs. Therefore, the company must* *implement an opportunity maintenance policy to make immediate corrective repairs to damaged parts found in preventive maintenance. This indication demands further investigation through failure rate analysis and the expected number of failures based on damage data obtained at PT.* PT. MI.

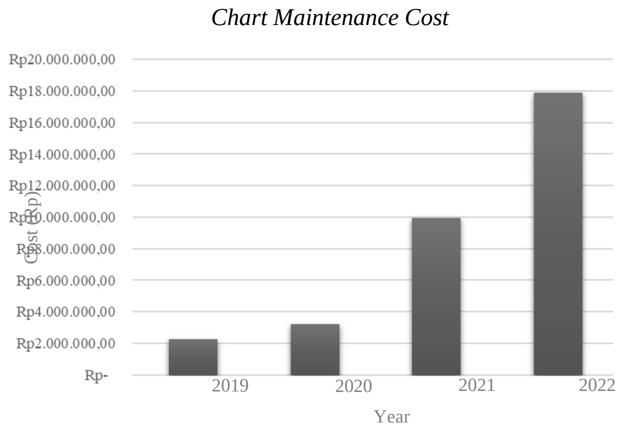

Figure 2. Maintenance Cost Chart

The chart in Figure 4.1 illustrates a notable rise in maintenance expenses over a while, which may be indicative of inadequate maintenance policies. Our forthcoming research endeavors to delve deeper into this matter by utilizing mathematical modeling and optimizing the model for better outcomes. Currently, we are conducting a thorough analysis to identify the underlying cause of the problem from a qualitative managerial perspective. To facilitate this analysis, we have created a fishbone diagram to explore various potential causes, and we are also utilizing Failure Mode and Effects Analysis (FMEA) tables.
The Fishbone Analysis in this study is based on the MIL-STD 882 standard. MIL-STD 882 is a standard used for system safety engineering and risk management within the military and defense sectors. It provides guidelines and procedures for identifying, assessing, and mitigating risks associated with systems, including potential hazards and failures. The utilization of MIL-STD 882 as the basis for the Fishbone Analysis ensures a structured and comprehensive approach to identifying and analyzing various factors that contribute to the identified problem, aligning with established safety and risk management practices within the defense domain.

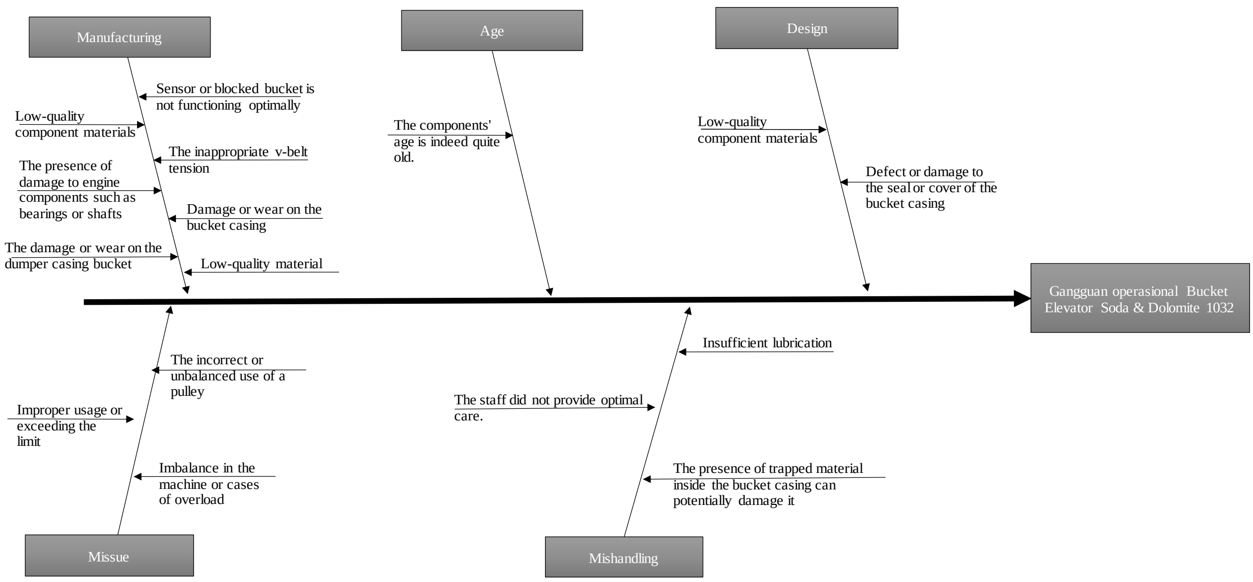

Figure 3. Chart Fishbone Problem Equipment bucket elevator soda and dolomite

Furthermore, Failure Mode and Effects Analysis (FMEA) will be conducted to identify and implement preventive or corrective actions to reduce the risk of failure and enhance the quality and reliability of the product according to the managerial perspectives. The risk emerged that potentially causes the failure are *reprented by Risk Priority Number (RPN). This term is a numerical value used in FMEA to measure the level of risk associated with a failure. The formula for the Risk Priority Number (RPN) are as follows* [17]:

$$RPN = Occurrence \times Detection \times Severity \quad (4)$$

Description:
Severity : *The score for the failure impact severity*
Occurrence : *The score for the frequency of failure occurrence*
Detection : *The score for the ability to detect failures before reaching the customer.*

Table 3. *Tabel Risk Priority Number*

RPN	***Risk Acceptability***	***Action***
1-14	*Low*	*Although the risk is low, mitigation still needs to be carried out.*
15-29	*Tolerable*	*If there is a redesign in the future, it is necessary to pay attention to this point to enhance the product's reliability.*
30-49	*Undesirable*	*The risk can still be accepted if it cannot be further mitigated by the organization or technology.*
>49	*Intolerable*	*The risk must be eliminated or reduced through protective measures.*

The higher the RPN value, the greater the level of risk associated with the failure. Here are the weights of each of the three factors.

1. *Occurrence*
   The occurrence is the likelihood that a cause will happen and that it will lead to detrimental consequences from the associated danger.

Table 4. *Score Occurrence*

Occurrence	
Category	***Score***
Certain to fail (1 failure per hour)	5
High number (1 failure per day)	4
Occasional (1 failure per week)	3
Few (1 failure per month)	2
Unlikely (1 failure per year)	1

2. *Detection*
   Detection is the probability that controls (design, processes, inspections, warnings, or alarms) will eliminate, reduce, or capture defects or failures.

Table 5. *Score Detection*

Detection	
Category	***Score***
Undetectable	5
Poor	4
Moderate	3
Good	2
Excellent	1

3. *Severity*
   Severity is a measure of the potential consequences and seriousness of a hazard.

Table 6. *Score Severity*

Severity	
Category	***Score***
Catastrophic	5
Critical	4
Serious	3
Minor	2
Negligible	1

The following are the results of FMEA (Failure Mode and Effects Analysis) and the highest RPN (Risk Priority Number) calculation, which is undesirable. The scoring are conducted according to the expert judgement consisting of 1 Superintendent, 1 Supervisor, and 3 Mechanical Staff.

Table 7. RPN and FMEA Calculation Results

NO	Failure Cause	Failure Classification	Failure Effect		O	D	S	RPN	Solution
			Component	System					
1	*Damage to engine components such as bearings or shafts*	*Design*	✓	✓	2,8	3,2	4,8	43	*Perform regular lubrication and use lubricants recommended by the manufacturer to maintain optimal engine performance. Perform regular cleaning around bearings and shafts to maintain cleanliness and prevent dirt accumulation. If you observe an increase in temperature or unusual vibration, check further immediately to avoid more serious damage.*
2	*Improper use or exceeding the load*	*Misuse*	✓	✓	3,4	3	3,4	34,68	*Install temperature and vibration sensors on bucket elevator machines to monitor operational conditions. Conduct regular monitoring and evaluation to ensure that the use of bucket elevator machines is by established standards. Improper use can result in damage to engine components and reduce their service life.*
3	*The lack of care and cleaning.*	*Mishandling*	✓	✓	2,2	4,2	3,8	35,11	*Perform routine visual inspections to identify signs of damage, dirt, or material buildup that may impede the performance of the bucket elevator machine. Take note of any indications of wear, leaks, or damage to machine components. Record all maintenance and cleaning activities carried out on the bucket elevator machine. Do not forget to document any findings or issues that arise during the inspection for appropriate corrective actions. Utilize a monitoring system to oversee the machine's performance in real time.*
4	*The staff is not providing optimal care.*	*Mishandling*	✓	✓	3,4	4,2	3,4	48,55	*Optimize staff monitoring while they are performing their tasks, and this can be achieved by utilizing RFID (Radio-Frequency Identification) technology.*

Based on the results of the FMEA (Failure Mode and Effects Analysis) table and RPN (Risk Priority Number) calculations, failure causes of staff who perform maintenance are not optimal is the main cause of an increase in maintenance costs on soda and dolomite 1032 *elevator bucket equipment during* 2019 *to* 2022. *So, the author has two solutions for companies as follows:*

1. *The company needs to monitor the activities of staff who carry out periodic checks on the company's machines, this is based on the results of making and calculating FMEA and RPN tables.*
2. *Based on a bar chart illustrating the increase in maintenance costs from year to year.* PT. MI *needs to review and improve the company's maintenance policy in the future. One approach is to create mathematical models to predict damage and maintenance costs. The model can then be opmtimized analytically or use a heuristic approach to achieve the best optimal results globally. The second solution will be the focus of subsequent research.*

The following is a picture of the RFID (Radio-Frequency Identification) technology scheme for monitoring staff who carry out machine maintenance that has been made by the author:

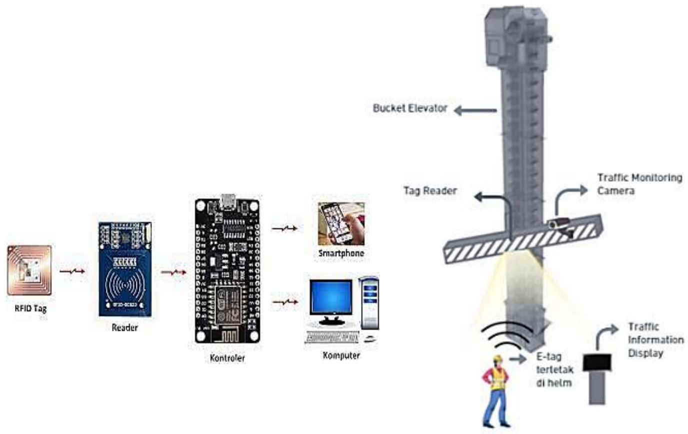

Figure 4. RFID (Radio-Frequency Identification) Scheme

The following is a description of the RFID (Radio-Frequency Identification) technology scheme for monitoring Staff who perform maintenance on bucket elevator equipment machines in a factory: RFID (Radio Frequency Identification) is used to monitor maintenance on bucket elevator equipment. Each staff member is assigned a unique RFID tag attached to their identity. RFID readers are installed near the equipment area and connected to the monitoring system. The monitoring system records the time and identity of the staff performing the maintenance. This data can be used for analysis, such as tracking maintenance time and staff productivity. Integration with care management systems (CMMS) enables structured reporting and efficient care scheduling. Using this scheme, companies can automatically monitor and record maintenance activities carried out by staff on bucket elevator equipment using RFID technology. This helps improve operational efficiency, ensures timely maintenance, and facilitates monitoring and reporting related to staff performing maintenance on bucket elevator equipment.

4. *CONCLUSION*

Conclusion

1. *The calculation results of MTBF and MTTR show that the optimal preventive maintenance schedule is 1 time in* 33 *days, with a difference of* 3 *days longer than the actual schedule. Early preventive repairs indicate damage that the company did not predict.*
2. *The soda and dolomite* 1032 *bucket elevator equipment experienced the most problems during* 2022, *with the cause of failure identified through FMEA analysis and RPN figures. It is necessary to monitor the activities of Maintenance Staff and review the company's maintenance policy.*
3. *The actual schedule of Preventive Maintenance is quite optimal schedule of Preventive Maintenance, but there is an increase in maintenance costs from* 2019 *to* 2022 *that needs to be analyzed.*
4. *This research will be the basis for future research on maintenance system optimization to minimize maintenance costs based on optimal Preventive Maintenance time.*

Suggestion

1. *Companies can further optimize worker monitoring by considering the use of RFID (Radio-Frequency Identification) technology as described in this study.*
2. *Companies in determining scheduling can race on maintenance policies and multiply literature references between the world of education and the industrial world, for example on theories obtained during lectures, and see continuity with real practice in the field.*
3. *Companies should upgrade the database system containing important documents or information so that it is neatly arranged and easy to find when needed.*
4. *Companies can consider optimal preventive maintenance schedules to prevent sudden failures and overcome increased maintenance costs.*

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