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| Optimization of Preventive Maintenance on Critical Machines at Sabiz 1 Plant Using Reliability-Centered Maintenance Method  |  |

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| ***Abstract*** *This study aims to optimize preventive maintenance planning for critical machines at the Sabiz 1 plant to minimize downtime and costs incurred for machine repairs and production losses. In this optimization, the Reliability Centered Maintenance (RCM) method is used with several sub-methods in it, such as FMEA to determine critical machines as the focus of analysis, fishbone to get the causes of failure, RCM worksheet to get preventive activities, and a statistical distribution approach to obtain appropriate preventive activity intervals. The result of data processing shows that all data has a lognormal distribution and can be continued using the lognormal distribution method. The results of this analysis are in the form of suggestions for preventive maintenance activities and their intervals as a reference. The results were obtained for three critical machines with each preventive maintenance activity and its interval, namely the high-pressure pump with 4 days of inspection activities and 2 days of replacement activities; the powder base conveyor with 4 days of checking activities and 17 days of replacement activities; and extraction tower fan with inspection activities at 7 days. The results show that this proposal has a savings prediction of around 70% compared to historical cost.**This is an open access article under the* [*CC BY-SA*](http://creativecommons.org/licenses/by-sa/4.0/) *license* | ***Keywords:*** *Downtime;* *Preventive Maintenance;**FMEA;**RCM;**Reliability Analysis****Article History:****Received:* *Revised:* *Accepted:* *Published:* ***Corresponding Author:****Sofia Debi Puspa**Mechanical Engineering Department, Universitas Trisakti Indonesia**Email:* *sofia.debi.puspa@trisakti.ac.id* |

**INTRODUCTION**

Reliability is the possibility of a machine performing its optimal function within a specific period under a given set of conditions. The concluded strategy must balance maintenance cost and plant reliability [1]**.** The system of reliability applies to all varieties of products, subsystems, equipment, components, and parts. When a product or system no longer performs its intended function, it is considered a failure. This can be a complete cessation of function, such as a machine shutting down or a structure collapsing, or it can be more subtle. To measure failure accurately, it is often necessary to define it quantitatively [2].

Reliability-centered maintenance (RCM) is a strategic framework designed to evaluate a system's maintenance requirements. While some industries rely on preventive maintenance (PM) and predictive maintenance strategies, these can often lead to increased production costs. By combining these strategies, RCM aims to optimize maintenance costs while ensuring the system remains available [3]. Reliability Centered Maintenance can be carried out by selecting effective maintenance strategies to offer reliability of spare parts. Product quality is better maintained because the production process goes according to plan. However, if a machine has low reliability or frequently breaks down, this will cause downtime, and the production process will be hampered [4].

In addition, this research conducted a comprehensive root cause analysis to identify all potential factors that could cause losses. This process involves using tools such as Failure Mode and Effects Analysis (FMEA). FMEA is expanding and has applications across different industries, such as manufacturing and services. This approach employs the Risk Priority Number (RPN) method and language-based terms to evaluate the severity, occurrence, and detection of potential risks [5].

The FMCG (Fast Moving Consumer Goods) industry is an industry that produces goods with high market demand. These products meet the basic needs of society, such as food, body care, clothing, hygiene, etc. To meet market needs that are increasing every day, the FMCG industry must optimize the efficiency of their production plants so that they can produce products according to the specified targets. The decrease in plant efficiency can be affected by the occurrence of downtime. One of the factors causing downtime is decreased machine reliability.

PT X is one of the FMCG industries that produces powder detergent products with various variants. To produce finished products, PT X has three primary plants in its production process. One of the plants that have a vital role is the Sabiz plant, which processes raw materials into detergent powder, ready to be transferred to the packing plant for packaging. The production team compiles downtime recording reports to obtain factory efficiency values and a CMMS designed to assist with the planning, management, and administration functions required for effective maintenance and recording of equipment failures [6].

The Sabiz plant is split into three segments: Sabiz 1, Sabiz 2, and Sabiz 3. The area of focus is determined based on the plant with the highest percentage of downtime. In 2022, Sabiz 1 demonstrated the lowest efficiency percentage, at 84.08%, and the highest percentage of recorded downtime, at 15.92%, compared to the other Sabiz plants. Thus, Sabiz 1 was selected as the primary research subject because it exhibited poor efficiency values, and reducing the recorded downtime is essential. The efficiency percentages for each Sabiz plant are shown in Figure 1.



Figure 1. Efficiency Percentage for Sabiz Plant

In a global era, the competitive global market is very high, so it is crucial to have effective strategies for ensuring productivity and efficient production. In order to address issues related to production problems and breakdowns in manufacturing companies, it is essential to conduct regular maintenance on machines [7]. Research conducted by [8] presents an optimal reliability-centered maintenance (RCM) strategy in power distribution systems. The study approach involved selecting the best strategy to optimize energy losses from the power supply and considering factors such as maintenance costs, safety and outage costs, and failure risks. This method tests effectiveness by analyzing various scenarios and examining the impact of variables such as maintenance time, safety costs, and practical limitations. The results show that implementing our approach can reduce total maintenance costs by at least 7% compared to applying the proposed method.

According to [9], RCM guarantees that an asset can continue to perform its function according to its current operating situation. This is achieved by identifying the asset's function potential failure modes that may prevent the asset from performing its intended function, prioritizing those failure modes, and determining practical preventive maintenance tasks that can be implemented cost-effectively and efficiently to reduce the likelihood of failure.

The reliability of railway systems is crucial, and FMEA analysis is a widely used technique for ensuring it. In a study by [10], researchers explored methods to apply FMEA to RCM procedures efficiently. This paper selected the AF Track circuit system as the target system, applied FMEA to ensure its reliability, and compared the results of using FMEA for system reliability and maintenance reliability. The analysis showed that using an approach based on maintenance reliability was more efficient in establishing a railway system maintenance system.

In addition, research was conducted by [11] using the FMEA maintenance optimization method for electric drive compressors. In order to maintain the compressor's performance at an optimal level, it is essential to strike a balance between achieving economic benefits and ensuring its reliability and availability. Neglecting maintenance can lead to costly repairs, while excessive maintenance can result in unnecessary expenses. Therefore, it is crucial to evaluate maintenance needs and perform only what is necessary to ensure the compressor functions efficiently and safely.

In preventing downtime, the purpose of maintenance is needed, where it has the function of monitoring and maintaining all the equipment by designing, organizing, handling, and inspecting work to ensure the function of the unit during uptime and minimize downtime caused by damage or repairs, so it can extend the usage time of equipment and reduce the cost of sudden repairs, start-up costs due to engine failure, and the cost of product defects due to engine damage [12].

Based on the previously described problems, this study optimizes preventive maintenance planning through analysis using a reliability-centered maintenance and FMEA method at Sabiz 1 Plant. By applying this method, the final result will be obtained in the form of proposed preventive maintenance activities that are right on target and at appropriate time intervals based on data processing and a statistical distribution approach as a reference. The Weibull, Exponential, Lognormal, and Normal distributions are selected to determine the probabilistic characteristics of the preventive maintenance interval from each equipment.

**METHOD**

For this study, we are utilizing the reliability-centered maintenance (RCM) approach, which focuses on enhancing the reliability and maintainability value. RCM is an essential and highly effective approach utilized to assess and optimize the maintenance needs of plants and equipment during operation. Its primary goal is to minimize equipment failures and enhance preventive maintenance strategies, allowing industrial plants to maintain their equipment efficiently and effectively [3].

The following is a brief overview of the RCM implementation process: Firstly, data is collected to determine the probability of occurrence and criticality assessment. In this case, it is important to record every machine defect in detail to obtain valid data for analysis. Second is identifying which machines have an important role and need to be the focus of maintenance. It is imperative to consider a range of factors when evaluating critical components. These factors consist of the frequency of damage, the impact of damage on the system, the assembly process's complexity, and the components' cost [4]. In addition, a thorough root cause analysis is conducted to identify all potential factors that may lead to harm. This process involves utilizing tools like FMEA (failure modes and effects analysis), which considers three parameters: severity (S), likelihood of occurrence (O), and probability of detection failure (detectability - D). The resulting RPN (risk priority number) helps to prioritize risks. The fishbone diagram is also employed, which outlines the six leading causes of problems, including machine malfunction, methods utilized, materials used, measurement processes, human resources, and environmental factors [13]. Third is the development of preventive maintenance activities using the RCM Decision Worksheet, which is then classified as preventive maintenance by calculating the accurate time intervals through a statistical approach to analyzing data distribution.

Analyze the damage data of components by calculating the time to failure (TTF) and time to repair (TTR) of important machines. Additionally, process the Index of Fit data on TTF and TTR data, using distribution approaches such as Weibull, exponential, lognormal, and normal exponential. The Weibull distribution is frequently utilized to assess the dependability of a system or component to determine its useful lifespan. The Weibull distribution has two key parameters: the characteristic life (θ) and the shape factor (β) values. The value of Beta (β) determines the shape of the distribution. If β > 1, the failure rate increases. If β < 1, the failure rate decreases. If β = 1, the failure rate remains constant [14]. The cumulative distribution function of the two-parameter Weibull distribution, as in (1). Reliability refers to the likelihood of an object or entity functioning as intended under specific conditions for a certain duration. The reliability function for the two-parameter Weibull distribution can be expressed as in (2).

 (1)

 (2)

Equation (3) displays the Weibull failure rate function, which is the expected number of failures per unit time for a given product.

 (3)

where β is shape parameter and θ is scale parameter.

Exponential distribution is commonly used in modeling reliability data due to its simplicity. The most used method for estimating the parameter of this distribution is the classical estimator, such as the maximum likelihood estimator, which is known for its efficiency. The exponential distribution implies that the likelihood of damage remains constant over time and is not affected by the age of the tool. The exponential distribution may be considered the specific case of the Weibull distribution with shape factor β = 1 and characteristic life θ = 1/λ. The cumulative distribution function, reliability function, and failure rate function of exponential distribution are shown as in (4), (5), and (6) respectively [15], [16].

 (4)

 (5)

 (6)

The lognormal distribution has many vital applications in economic, biological, and reliability engineering. In practical problems, the lognormal distribution is more suitable for data modeling than the normal distribution, especially in small samples [17]. A lognormal distribution is a type of continuous probability distribution for a random variable, in which the logarithm follows a normal distribution. This type of distribution is commonly used to describe fatigue failure, failure rates, and other phenomena that involve a wide range of data [18]. The density function of lognormal distribution is given as (7).

 (7)

The formula for the cumulative distribution function of lognormal distribution as in (8).

 (8)

where 𝜱 is the cumulative distribution function of the normal distribution.

 The reliability of items that experience wearout failures can be modeled using the normal distribution. To determine the reliability at a specific point in time , the mean life and standard deviation are required. Probability density function and reliability function of normal distribution are given as (9) and (10) respectively [19].

 (9)

 (10)

To obtain a value that can be used for MTTF (Mean Time to Failure) and MTTR (Mean Time to Repair) calculations, the distribution calculation results should be identified based on the largest fit value index. Afterward, the results should be tested for goodness of fit. Calculation in determining the level of damage or repairs required for a component and estimating the duration of the repairs, utilize the least square curve fitting method [20]. Equation (11) displays the least squares curve fitting formula.

 (11)

The Mean Time to Failure (MTTF) refers to the average duration or time it takes for damage to occur. It represents the working period of a component from its initial use or activation to the point where it becomes damaged. Depending on the type of damage distribution, MTTF is calculated differently for each instance of damage data [21]. The calculation for each distribution is as follows:

1. Weibull Distribution

 (12)

where is scale parameter and is shape parameter; obtained from Gamma function.

1. Exponential Distribution

 (13)

where is failure rate.

1. Lognormal Distribution

 (14)

where is median (a scale parameter) and is shape parameter.

1. Normal Distribution

 (15)

where is mean value.

Mean time to Repair (MTTR) is the average value or average time needed to repair a damaged component (breakdown). MTTR affects system availability by impacting downtime. A lower MTTR means faster repairs and recovery [21] MTTR calculation for each distribution is stated as follows.

1. Weibull Distribution

 (16)

where is scale parameter and is shape parameter; obtained from Gamma function.

1. Exponential Distribution

 (17)

where is failure rate.

1. Lognormal Distribution

 (18)

where is median (a scale parameter) and is shape parameter.

1. Normal Distribution

 (19)

where is mean value.

Once the MTTF and MTTR have been calculated, the next step is determining the replacement time interval using the age replacement method. Age replacement is a method of preventive replacement that is based on the age of a component. Its purpose is to determine the optimal time for preventive replacement based on the age of the component. The calculation for the replacement time interval is based on the lowest downtime value of ) [22].

**DATA COLLECTION**

For this study, we analyzed engine damage data from January 1, 2022, until December 31, 2022, that was tracked on SAP, a CMMS. Our focus was on Sabiz 1, a plant with around 200 pieces of equipment that are crucial to the production process. Using various parameters, we identified the critical machine for our research. One key factor was the equipment that caused the most extended downtime due to damage. This mattered because it affected the plant's operations and ultimately hindered the achievement of production targets. As a result, this equipment needed extra attention.

The equipment with the highest frequency of damage is an important parameter to consider. This indicates a need for analysis to determine the causes of frequent damage and to give the equipment special attention. Using historical data on equipment damage from SAP, we found ten equipments that require the parameter above. Three units of equipment were selected that contributed to the top downtime duration as the main objects of research and were referred to as critical machines, namely the high-pressure pump, which contributed 188 hours of duration and 117 times failures occurred; conveyor base powder, with a duration of 52 hours and 11 failures occurred; and extraction air tower, with a duration of 93 hours and times failures occurred. Furthermore, obtain failure time data for critical machines from SAP. Table 1 displays a sample of high-pressure pump data.

Table 1. Failure Time Data of High-Pressure Pump

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **No** | **Date** | **Start Time** | **Finish Time** | **Dur (Min)** |
| 1 | 04/01/2022 | 14:30 | 15:30 | 60 |
| 2 | 12/01/2022 | 06:30 | 08:00 | 90 |
| 3 | 15/01/2022 | 10:30 | 11:35 | 65 |
| **:** | **:** | **:** | **:** | **:** |
| 115 | 21/11/2022 | 10:00 | 16:00 | 360 |
| 116 | 29/11/2022 | 11:00 | 12:00 | 60 |
| 117 | 29/12/2022 | 22:30 | 23:48 | 78 |

**RESULTS AND DISCUSSION**

**Potential Failures Identification**

At this step, an analysis is carried out to find out what the potential failures are that occur most frequently in each of the critical machines that have been previously selected. FMEA considers severity, occurrence, and detection in determining the potential failure by calculating the RPN (SxOxD). The following is an explanation of the failure modes of the components, referring to the highest RPN value for each piece of equipment. The high-pressure pump has v packing set and plunger as the components with the highest RPN (75), which means they are considered the most frequent reasons for failure. Conveyor base powder has a conveyor belt as the component with the highest RPN (20), which is considered the most frequent reason for failure. Extraction tower fans have blowers as the component with the highest RPN (40), which is considered the most frequent reason for failure.

**Root Cause Analysis**

The root cause analysis stage is carried out to determine the failure causes in each of these critical machines. In determining the cause of failure, a fishbone diagram is used. The following is a fishbone showing the causes of failure in each piece of equipment, shown in Figures 1, Figure 2, and Figure 3.



Figure 1. Fishbone for High-Pressure Pump

Figure 2. Fishbone for Conveyor Base Powder

Figure 3. Fishbone for Extraction Tower Fan

**RCM Worksheet**

Based on the previous analysis, it is necessary to determine what actions will be taken to reduce the possibility of damage.In looking for actions that can be decided for the causes of component damage to each equipment, the RCM Decision Worksheet is used, described previously. From the RCM Decision Worksheet, the proposed task for the high-pressure pump is cleaning the cooling line and frequently replacing the v-packing set based on the reliability calculation. The proposed task for conveyor base powder is checking the thickness of the conveyor belt and pressing the connection of the conveyor belt frequently based on the reliability calculation. The proposed extraction tower fan task is checking the blowers' vibration, shaft alignment, and mounting condition.

**Failure Duration Calculation**

RCM Worksheet has found the task for preventive maintenance, and the next step is calculating the failure time for each component to get the suitable interval for preventive maintenance. The first step is calculating failure duration by calculating the difference between the end time and the start time of the failure. For example, the calculation for failure on January 4, 2022, is 14:30 – 15:30 = 60 minutes. After calculating the duration, the next step is the calculation of time to failure and time to repair concerning these points:

1. As a sample, high-pressure pump failure time data is used on January 12, 2022, and January 15, 2022. TTF will be calculated on January 15, referring to the damage that occurred on January 12, 2022. The TTF on January 4, 2022, cannot be searched because that date is the first day of equipment damage in 2022.
2. Sabiz plant operates from Monday to Saturday. Meanwhile Sunday, the plant stops, so in this calculation, Sunday (for 24 hours) is not included.
3. Notice the failure that occurred on January 12, 2022. Things that we need to look for are the duration interval, which is calculated from the hour when the failure occurs, which is 08:00 on January 12, 2022, until the end of the day on January 12, 2022, which is 00:00. Then, between 08:00 on January 12, 2022, and 00:00 on January 12, there are 960 minutes.
4. Pay attention to the damage that occurred on January 15, 2022. Things that we need to look for are the duration interval, which is calculated from the end of the day on January 14, 2022, which is 00:00, until the start of the damage, which is 10:30. Then, between 00:00 on January 15, 2022, and 10:30 on January 12, there are 630 minutes.
5. The total number of days the equipment operates is calculated. Calculates days from the start of the damage until the damage occurs again without counting Sundays. Between January 12 and January 15, 2022, there are four days. Because in steps 3 and 4, the duration has been searched for on January 12 and January 15, each day's calculation will be reduced by 2. Then an interval of days is found, which is two days or 2880 minutes.
6. The last thing is the sum of the durations found in stages 3, 4, and 5. TTF results on January 15 are based on calculations, namely 960 minutes + 630 minutes + 2880 minutes = 4470 minutes.
7. The steps above are applied to each TTF calculation for each date referring to previous damaged data. The following are the results of calculations for the high-pressure pump which is shown in Table 2.

Table 2. TTF Calculation for High-Pressure Pump



**Distribution Identification**

In the next step, we will process the TTF and TTR data from each high-pressure pump, conveyor base powder, and extraction tower fan data to determine the appropriate distribution using Minitab software. We will be using four distributions namely Weibull, exponential, lognormal, and normal. Tables 3 and Table 4 will display the Anderson Darling values and correlation coefficient on the TTF and TTR data.

Based on Table 3 and Table 4, it was found that the lognormal distribution had the highest correlation coefficient value compared to other distributions for TTF data on all three equipment. Additionally, the lognormal distribution also had the lowest Anderson-Darling value. Based on these findings, the lognormal distribution was selected as the optimal distribution for the TTF data on all three equipment.

Table 3. Index of Fit of TTF Data

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment** | **Selected Distribution** | **Anderson-Darling**  | **Correlation Coefficient** |
| High-Pressure Pump | Lognormal | 0,089 | 0,983 |
| Conveyor Base Powder | Lognormal | 1,584 | 1,345 |
| Extraction Tower Fan | Lognormal | 0,640 | 0,993 |

Table 4. Index of Fit of TTR Data

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment** | **Selected Distribution** | **Anderson-Darling** | **Correlation Coefficient** |
| High-Pressure Pump | Lognormal | 10,687 | 0,871 |
| Conveyor Base Powder | Lognormal | 1,345 | 0,975 |
| Extraction Tower Fan | Lognormal | 1,412 | 0,965 |

The next stage of identification of the distribution is the goodness of fit test to prove that the determination of the distribution in the index of fit is suitable for use in the analysis. The following is the goodness of fit test hypothesis:

: The data follows a lognormal distribution.

: The data does not follow a lognormal

 distribution.



Figure 4. Goodness of Fit Test for

High-Pressure Pump TTF Data

The goodness of fit results in Figure 4 show that the most significant p-value and the smallest AD value are in the lognormal distribution. In addition, the p-value (0.053) > (0.05); therefore, there is insufficient evidence at the 5% level to reject . Hence, the data follows lognormal distribution. Figure 4 displays the goodness of fit results for TTF high-pressure pump data as a sample. Table 5 contains the complete goodness of fit results for all TTF data, which indicates the selection of a lognormal distribution.

Table 5. Distribution Selected for Each

TTF Equipment

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment** | **Fit Distribution** | **P Value** | **AD** |
| High-Pressure Pump | Lognormal | 0,053 | 0,738 |
| Conveyor Base Powder | Lognormal | 0,313 | 0,389 |
| Extraction Tower Fan | Lognormal | 0,899 | 0,184 |



Figure 5. Goodness of Fit Test for Conveyor Base Powder TTR

Furthermore, as a sample, the TTR conveyor base powder data shows that the lognormal distribution has the largest p-value with the smallest AD value (see Figure 5). In addition, the calculated p-value (0,576) is higher than (0.05) ,so there is insufficient evidence to reject . Hence, the data follows a lognormal distribution. Based on the goodness of fit results shown in Table 6, the lognormal distribution is the most suitable fit distribution. Therefore, the MTTF and MTTR calculations will be conducted according to the lognormal distribution rule.

Table 6. Distribution Selected for Each TTR Equipment.

|  |  |  |  |
| --- | --- | --- | --- |
| **Equipment** | **Fit Distribution** | **P Value** | **AD** |
| High-Pressure Pump | Lognormal | 0.062 | 10,448 |
| Conveyor Base Powder | Lognormal | 0,576 | 0,278 |
| Extraction Tower Fan | Lognormal | 0,052 | 0,950 |

In order to calculate the MTTF and MTTR, certain parameters must be determined by processing the data. Table 7 provides an example of how to determine the necessary parameters for calculating MTTF for high-pressure pump data. The same calculation process applies to other equipment.

Table 7. Calculation of High-Pressure Pump MTTF Parameter

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **i** | **ti** | **xi=ln(ti)** | **ln(ti)-t** | **(ln(ti)-t)2** |
| 1 | 9540 | 9,163 | 1,385 | 1,917 |
| 2 | 4470 | 8,405 | 0,627 | 0,393 |
| 3 | 3025 | 8,015 | 0,236 | 0,056 |
| **:** | **:** | **:** | **:** | **:** |
| 115 | 9780 | 9,188 | 1,409 | 1,987 |
| 116 | 38070 | 10,547 | 2,769 | 7,665 |
| **∑** | **457275** | **902,319** | **0,000** | **91,693** |

Based on the table, the following calculation can be obtained:

 =

 =

= 7,779

tmed =

= 2388,959

s =

= = 0,889

MTTF = tmed

 = 2388,959. = 3546,944

The following is the result of all MTTF and MTTR for each equipment, shown in Table 8.

Table 8. MTTF and MTTR for Each Equipment

|  |  |  |
| --- | --- | --- |
| **Equipment** | **MTTF (hr)** | **MTTR (hr)** |
| High-Pressure Pump | 59,116 | 1,547 |
| Conveyor Base Powder | 508,452 | 7,196 |
| Extraction Air Tower | 344,050 | 3,529 |

**Determination of Preventive Maintenance Interval**

The determination of preventive maintenance is divided into two categories: check activity and replacement activity.

The following is a sample calculation of interval of preventive maintenance with check activity for high pressure pump.

1. Working Hours average in a month
* Working hours in a month = 20 days
* Working hours in a day = 24 hours
* Working hours average in a month = 20 x 24 = 480 hours.
1. Failure Frequency

Failure frequency in a period (12 month in 2022) = 117 times.

1. Average repair time

 =

 = 310,314

1. Average Check Time

Duration for check activity (ti) = 30 minutes = 0,5 hours.

 = =

i = 960

1. Average of Failure

k =

 = 9,75

1. Optimum Check Frequency

n = = = 5,492

1. Check activity interval.

 = = 87,3 jam

Hence the preventive maintenance interval for check activity is 87,3 hours, or 4 days. The same step was also carried out for finding interval for check activity of conveyor base powder and extraction tower fan.

The following is the sample calculation of interval of preventive maintenance with replacement activity for high-pressure pump. Before the calculation is carried out, it is necessary to know some of the parameters that have been previously obtained, as follows.

 = preventive time interval in the

 calculation, 45 hours will be chosen as

 the interval, so the sample calculation

 will use 45 hours).

s = 0,899

 = 2388,959 min = 39,816 hours

MTTF = 3546,944 min = 59,116 hours

MTTR = Tp = Tf = 92,809 min= 1,547 hours

 = cumulative distribution function of the

 normal distribution

Based on those parameters, the calculation of ) (total downtime per unit time for replacement activity) can be started in the following step.

) =

 =

 = = 0,5547469

) = = 1 - = 0,445

) = = = 106,564

) =

 =

 = 0,0191699

Table 9. Age Replacement for

High-Pressure Pump

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | ) | ) | ) | ) |
| 40 | 0,50206 | 0,497931 | 117,744 | 0,0191983 |
| 41 | 0,51314 | 0,486854 | 115,203 | 0,0191878 |
| 42 | 0,52394 | 0,476053 | 112,828 | 0,0191799 |
| 43 | 0,53447 | 0,465523 | 110,605 | 0,0191744 |
| 44 | 0,54474 | 0,455258 | 108,521 | 0,0191711 |
| 45 | 0,55474 | 0,445253 | 106,563 | 0,0191699 |
| 46 | 0,56449 | 0,435501 | 104,723 | 0,0191707 |
| 47 | 0,57400 | 0,425997 | 102,989 | 0,0191734 |
| 48 | 0,58326 | 0,416735 | 101,353 | 0,0191778 |
| 49 | 0,59229 | 0,407708 | 99,808 | 0,0191839 |

As shown in the Table 9, the calculations were carried out using 1-59 hours because it is referred to the MTTF value until the smallest ) is found. Based on all the calculations found that the smallest value of ) is 0,0191669, so it can be concluded that the preventive maintenance interval for replacement activity is 45 hours, or 2 days. The same step was also carried out for finding interval for replacement of conveyor base powder and extraction tower fan.

Based on the calculation of intervals for checking and replacing activities using the same method as before, the results of the analysis of preventive activities that have been submitted previously through the RCM Worksheet can be summarized in Table 10. The interval for replacing activity of extraction tower fan was not included because by checking the vibration of blowers is enough to monitor the condition of it and we can easily find the abnormality because of the intense of checking.

Table 10. Proposed Preventive Activities and Time Intervals

|  |  |  |
| --- | --- | --- |
| **Equipment** | **Proposed Preventive Maintenance** | **Time Interval** |
| High-Pressure Pump | Cooling line cleaning | 4 Days |
| Replacement of plunger and v packing set | 2 Days |
| Conveyor Base Powder | Checking the thickness of conveyor belt | 7 Days |
| Pressing the connection of conveyor belt | 17 Days |
| Extraction Air Tower | Checking the vibration of blowers and checking the shaft alignment and mounting condition | 7 Days |

**Cost Comparison**

PT X provided data that indicates Sabiz 1 has an estimated breakdown rate of Rp. 20,000 per minute. This value is calculated based on various factors, including the depreciation of Sabiz 1's assets, energy consumption (such as electricity and air), and labor costs. This information is used to determine the cost of downtime losses in minutes.

If the preventive maintenance is implemented, the percentage of savings is expected to decrease by around 68% for high-pressure pumps from IDR 694.648.958 in 2022 to Rp219.000.000 in 2024, with a savings rate of IDR 475.648.958 and by around 75% for conveyor base powder from IDR 273.448.958 in 2022 to IDR 67.200.000 in 2024 with a savings rate of IDR 206.248.958.

**CONCLUSION**

Three critical machines have been found: a high-pressure pump, a base powder conveyor, and an extraction tower fan. Failure modes were found for each critical machine: the high-pressure pump with leakage failure of the v packing set, base powder conveyor with tear conveyor belt failure, and extraction tower fan with high blower vibration failure. The analysis shows that the processed data has the highest correlation value and the lowest Anderson Darling value in the lognormal distribution, so the distribution chosen to continue data processing is the lognormal distribution. Based on the data processing, it was found that appropriate preventive maintenance activities for each critical machine were: high-pressure pumps with cooling line cleaning activities (4 days) and v packing set replacement (2 days); conveyor base powder with the activities of checking the thickness of the conveyor belt (7 days) and pressing the conveyor belt joints (17 days); extraction tower fan by checking the vibration of the blower, mounting, shaft, and impeller (7 days). By implementing preventive maintenance, it can be simulated that it can reduce costs incurred compared to before optimization was carried out. The percentage of savings is expected to decrease by around 68% for high-pressure pumps and around 75% for conveyor base powder.

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