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Design Maintenance System on Mixer Machine to Prevent the Breakdown Using Reliability Centered Maintenance

Budhi Santri Kusuma[1,*], Mhd. Ardian Syahputra[1], Roaida Yanti[2], Dede Ibrahim Muthawali[3]
[1] Department of Industrial Engineering, Faculty of Engineering, Universitas Medan Area, Medan
[2] Department of Industrial Engineering, Faculty of Industrial Technology, Universitas Islam Indonesia, Yogyakarta
[3] Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Sumatera Utara, Medan
Email: budhi@staff.uma.ac.id

Abstract

Equipment, machinery, and labor are fundamental assets of an organization. Therefore, companies must have an appropriate and scheduled maintenance system. However, many manufacturing companies neglect maintenance, leading to frequent machine breakdowns that can result in machine downtime and financial losses. This research aims to determine the machine maintenance interval and the types of actions to be taken. The method employed is Reliability Centered Maintenance with the Failure Mode and Effect Analysis approach to identify failure patterns in a system and formulate the best strategies for designing a maintenance system. The results indicate that the CS-20 Type B mixer is the most critical machine, which can significantly reduce the company's production output due to machine downtime during the repair process. Based on the Reliability Maintenance method, the maintenance interval for components with potential failures is 273.17 hours for the bearing component, experiencing breakdowns three times with the highest damage occurrence within one year.

Keywords : FMEA; Machine Maintenance; RCM

INTRODUCTION

Along with the rapid technological changes and industry competition, organizations are adopting different strategies and policies to enhance productivity and reduce costs. Today, businesses face global competition (Azid, Shamsudin, Yusoff, & Samat, 2019). The high level of competition among industries and the business world has intensified the struggle for survival (Okwuobi, et al., 2018). Every organization must improve or at least maintain its assets to remain competitive. Equipment, machinery, and labor are fundamental assets of any organization (Jafarpisheh, Karbasian, & Asadpour, 2021). However, special attention must be given to improving machine efficiency and reducing failure costs. An organization's success in providing services and enhancing quality depends on various factors. Among these factors, one of the most crucial for an organization is having an appropriate maintenance and repair system (Carpitella, et al., 2020), which must be achieved through the most suitable and practical approach.

Maintenance is a routine task performed repeatedly to keep equipment functioning. Maintenance is a crucial key influencing equipment's operating time and efficiency (Carvalhoa, et al., 2019). Many studies on reliability and maintenance strategies have been developed over the years to ensure the smoothness of the production process by guaranteeing production continuity and product quality. Leading management can face the status quo challenge by reevaluating maintenance strategies and decision-making efforts to understand various maintenance policies that enable better asset maintenance (Wakiru, Pintelon, Muchiri, & Chemweno, 2019).

The decision-making method widely applied is Reliability Centered Maintenance (RCM) (Sakib & Wuest, 2018). RCM is a systematic method to secure all facilities to operate by their design and functions (Sajaradj, Huda, & S., 2019). RCM is typically used to study failure patterns in a system, enabling decisions about the best strategy to be applied to ensure that a system achieves the desired levels of operational reliability, safety, and readiness, and subsequently, environmental safety in the most economical manner (Suryono & Rosyidi, 2018). RCM is also a systemic consideration for maintenance practices' functionality, failures, safety, and cost-effectiveness (Majuru, 2021). It is a process that can determine what needs to be done to ensure the availability of machines performing their desired functions efficiently. Over 40 years of RCM implementation, it has been tested and confirmed as an effective strategy for optimizing preventive maintenance (PM), an increasingly popular method in various industrial settings.

A bread manufacturer has a mixer machine to mix the raw ingredients in production. Based on observations, it was found that maintenance for this mixer machine is rarely conducted, leading to frequent breakdowns. Consequently, this company often faces machine breakdown conditions that hinder production. Breakdown conditions occur when damage to components is found in the machine, affecting its performance capabilities. Furthermore, this can result in a decrease in production output and product quality. This company has two mixer machines: Mixer A Type B-15 and Mixer B Type CS-20. Data on the frequency of breakdowns for each device were obtained based on the percentage of their downtime. The total frequency of breakdowns for Mixers A and B per year reaches 44% and 55%, with the highest breakdown times being 12.39 hours and 15.42 hours, respectively.

Based on the problem description above, this research proposes a machine maintenance system using the RCM method. The system will be identified by determining the machine maintenance time interval to minimize mixer machine downtime, establishing the added value of critical component reliability, and determining the frequency interval of mixer machine breakdowns. The RCM method is expected to establish more structured maintenance activities for each machine component, particularly the mixer machine. The advantages of RCM as a structured approach to determining optimal maintenance phases are achieved through detailed Failure Mode and Effects Analysis (FMEA) analysis measures.

FMEA is a systematic approach to identifying and preventing problems in systems, products, and processes before they occur (Teplická, Seňová, Hurná, & Szalay, 2021). It focuses on problem prevention, enhancing safety, and improving customer satisfaction. FMEA is widely used in the manufacturing industry across various product life cycle phases and is employed in various industries, including semiconductor processing, food services, plastics, power generation, software, and healthcare. Successful FMEA activities enable teams to identify potential failure modes based on past experiences with similar products or processes. This allows the team to design out these failures from the system with minimal effort and resource expenditure, thereby reducing development time and costs (Sharma & Srivastava, 2018). Although the primary goal of RCM is to determine maintenance costs, the analysis results can also be used to determine the priorities set for improvements.

Previous research by Marpaung et al. (2021) examined the use of RCM to design preventive maintenance systems in product design labs. Such research has shortcomings, i.e., some facilities need to have real historical data so that FMEA variable values in particular events (O) and detection (D) are obtained by way of estimation. According to Setiawan et al. (2019), research on maintenance relies heavily on the completeness and accuracy of the data. In his research, he recommended further research to design machine failure recording systems and maintenance data, especially in small and medium-sized enterprises. Based on empirical research on these studies, the novelty of this research is to research maintenance in small and medium-sized enterprises with complete historical data on the machine to be studied.

LITERATURE REVIEW

1. Maintenance

Maintenance is the process of monitoring and maintaining an object, typically associated with machines in the industrial context. The maintenance of machines has an impact on the overall production process. Machine maintenance systems are designed to provide a maintenance schedule with minimal downtime and minimized costs. Maintenance is divided into two types: preventive maintenance and predictive maintenance. Preventive maintenance is a planned maintenance activity based on historical data to ensure the regular operation of the machine. On the other hand, predictive maintenance involves activities on specific machine parts based on actual conditions when damage to the machine is detected (Abiad, Kadry, & Lonescu, 2018).

2. Reability Centered Maintenance (RCM)

RCM is a method that can be used to analyze and determine the maintenance activities required to keep a specific piece of equipment or machinery in optimal condition. RCM enables the selection of appropriate maintenance tasks and reduces the likelihood of process failures (Alrifaey, Hong, As'arry, Supeni, & Ang, 2020). According to Azid et al. (2019), their study mentioned several advantages and benefits of RCM, such as improving system reliability, ensuring better safety and environmental outcomes, and achieving greater cost efficiency.

3. FMEA

FMEA is an inductive and bottom-up approach that can be used to identify errors, impacts, and causes in a system, which can help determine the severity of the failure mode based on the RPN, which includes several Metrics of Gravity (S), Occurrence (O), and Detection (D) (Cristea & Constantinescu, 2017). FMEA offers lower project costs, shorter project durations, and enhanced product quality and dependability (Sharma & Srivastava, 2018).

4. Downtime

Downtime is when a specific component or system is in an unfavorable condition and cannot be operated according to its function. Downtime is caused by machine breakdowns (failures) that impact efficiency in the production line. Furthermore, downtime is the time interval from the onset of a failure until it can be operational again (Yousef, Coit, Song, & Feng, 2019). There are two common conditions: choosing the maintenance frequency to reduce downtime due to maintenance due to increased downtime due to failures or increasing the maintenance frequency to enhance downtime due to maintenance with the consequence of reduced downtime due to failures.

Conceptual Framework

A conceptual framework can be defined as a model of how theory relates to various factors identified as important issues. Machine downtime is when a machine or equipment cannot operate due to a malfunction. Therefore, downtime is influenced by the frequency of machine failures and the duration of machine repair. The proper machine maintenance interval can be formulated from machine downtime data to achieve more scheduled maintenance, which is calculated using the RCM method. Determining the appropriate maintenance interval is crucial because short intervals result in high and low damage costs. However, long intervals lead to high damage costs and low maintenance costs. This is because the better the maintenance, the higher the maintenance costs. Meanwhile, the cost of downtime due to failures decreases with the increase in maintenance quality. Therefore, optimal maintenance actions are needed in terms of both maintenance and damage costs.

The conceptual framework used in this study is illustrated in Figure 1.

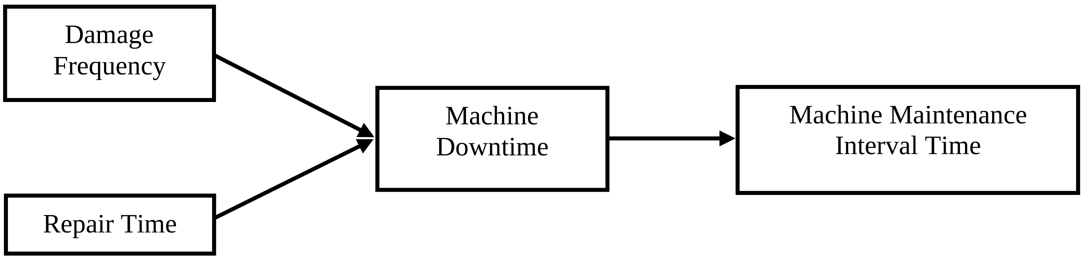

Figure 1. Conseptual Framework

METHOD

This research was conducted at one of the bakery companies in Medan, Indonesia. Data collection was carried out through direct observation and interviews. The collected data included machine failure data and the time needed for repairs. The research data spanned one year, from May 2021 to May 2022, and was a reference for determining the time maintenance intervals. After the data is collected, data processing is carried out, which is helpful as a reference in analyzing problems and determining appropriate improvement proposals to be implemented. The method used in this study is RCM to identify failure patterns of a system and formulate the best strategy for designing a maintenance system. The FMEA approach was also employed to determine the level of damage to a component, enabling preventive efforts to be initiated as early as possible.

Data processing in this study was carried out in several stages:

1. Data Adequacy and Uniformity Test

$$\sigma = \sqrt{\sum \frac{(x - xi)^{2}}{N-1}} \quad (1)$$

$\bar{X}$ = Average
xi = Data *i*th

2. FMEA

To identify the primary causes of failure for each failure that occurs in a component, an analysis is conducted using FMEA with several stages, namely:

a. Failure identification
b. Machine function failure identification
c. Failure mode identification
d. Failure effect identification
e. Severity calculation
f. Occurrence calculation
g. Detection calculation
h. RPN calculation

The formula for the calculation in this FMEA is as follows:

RPN = S x O x D

S = Severity
O = Occurance
D = Detection

3. Machine and Component Downtime Calculation

Downtime Percentage

$$\%\ \text{Downtime} = \frac{\text{Machine Downtime}}{\sum \text{Downtime}} \times 100 \quad (2)$$

4. Time to Failure (TTF) and Time to Repair (TTR) Calculation.

The calculation is done by measuring the time interval from the occurrence of damage to the repair and subsequent malfunction.

5. Mean Time to Failure (MTTF) and Mean Time to Repair (MTTR) Calculation

- Parameter Formula

$$a = \frac{n \sum_{i=1,2}^{n} xiyi - (\sum_{i=1,2}^{n} xi)\ \sum_{i=1,2}^{n} yi}{\sqrt{\left[n \sum_{i=1,2}^{n} xi^2 - \left(\sum_{i=1,2}^{n} xi\right)^2\right]}} \quad (3)$$

- MTTF and MTTR formula

$$MTT = \beta \left(1 + \frac{1}{a}\right) \quad (4)$$

- Reability of the component

$$R(t) = e - \left(\frac{t}{\mu}\right) \beta \quad (5)$$

6. Calculation of maintenance time interval

- Average repair time

$$\frac{1}{\mu} = \frac{\text{MTTR}}{\text{Average working hours per month}} \quad (6)$$

- Average downtime

$$\frac{1}{\mu} = \frac{\text{Average inspection}}{\text{Average working hours per month}} \quad (7)$$

- Average failure

$$\text{k} = \frac{\text{Number of failure in one year}}{12} \quad (8)$$

- Optimal inspection frequency

$$n = \sqrt{\frac{k \times i}{\mu}} \quad (9)$$

- Failure time interval

$$ti = \frac{\text{Average working hours per month}}{n} \quad (10)$$

RESULT AND DISCUSSION

1. Data Adequacy and Uniformity Test

This data adequacy test determines whether the data obtained is objectively sufficient. Data is considered adequate if the value N > N'. Table 1 shows the data adequacy test results for each machine.

Tabel 1. The result of data adequacy test

Machine Type	N'
Mixer A Type B-15	3,84
Mixer B Type CS-20	3,76

Based on the calculation of the data adequacy test above, the result was that the N' value for mixer A was 3.84 and for mixer B was 3.76. Both results are more significant than the N value or 13, so it can be concluded that the data is sufficient to represent the observed population. Both results are more significant than the N value or 13, so it can be concluded that the data is sufficient to represent the observed population.

After this, the uniformity test is helpful to see whether the collected time measurement data is uniform. The uniformity test uses the upper control limit (UCL) and lower control limit (LCL). Based on the calculations using the formula in equation 1, the BKA value is 60.94, and the BKB is 50.14, so it can be concluded that all data is uniform.

2. FMEA

This FMEA calculation aims to identify the failures in the Mixer Machine during the production process. The RPN rating values are used to determine these failures, including severity, occurrence, and detection indicators. In this stage, an analysis is conducted to identify the components in Mixer Machine B CS-20 with the highest failure rating percentage.

Tabel 2. FMEA on the CS-20 type B mixer machine

Part	Function	Potential Failure Mode	Potential Effect of Failure	S	Potential Cause of Failure	O	Current Controls	D	RPN
Belt	Connec-ting Two Rotating Shafts	Belt frequently breaks	Belt breaks	5	Usage factor	5	Performing belt replacement	4	100
Bear-ing	Reducing friction	Some bearing parts are damaged	Bearing breaks	7	Component lifespan factor	8	Conducting inspections	3	168
Switch on/off	Turning on and off an electrical device	Switch on/off frequently malfunction	Button malfunction	9	Usage factor	2	Replacing the on/off switch button	4	72
Dynamo	Adjusting rotation speed	Dynamo is burnt	Burnt	8	Emergency	4	Must be replaced immediately	2	64
Pulley	Connec-ting the rotation from the electric motor to the belt	Pulley is damaged	Experienc-ing wear and tear	2	Component lifespan factor	4	Conducting inspections	5	40
Gear	Gear Drive	Gear surface often damaged	Gear damaged	9	Component overload	5	Regular inspections	2	90
Conta-iner	Material displace-ment	Leaking Container	Leakage	9	Component lifespan factor	3	Conducting inspections	2	54
Screw	Binder for two objects	Screw component broken	Broken screw	6	Usage factor	4	Replacing the component	3	72
Stirrer Feet	Balancing	Stirrer feet on the machine are broken	Support leg broken	4	Accidentally damaged	3	Inspection every 2 days	4	48
Stirring Pole	Buffer	Stirring pole has been bent	Buffer pole bent	1	Touched by another objec	10	Daily inspection	4	40

Based on Table 2 above, the results of the RPN calculation for each component in Mixer Machine Type B CS-20 can be determined. A high RPN value indicates that the component has a high level of failure and affects the production process using Mixer Machine Type B CS-20. It can be observed that the bearing component has the highest RPN value compared to other components, amounting to 168.

Tabel 3. Component downtime

No	Component	Downtime (Hour)	Downtime (%)	Cumulative (%)
1	Belt	2,01	20	20
2	Bearing	2,79	27	47
3	Switch on/off	0,57	5	52
4	Dynamo	0,52	5	57
5	Pulley	0,56	5	62
6	Gear	0,59	6	68
7	Container	1,03	10	78
8	Screw	1,00	9	87
9	Stirrer Feet	0,52	5	92
10	Stirring Pole	0,43	4	96
Total		10,02	96	

Based on the results of the downtime calculations for each component above, it can be seen that the bearing component has the highest downtime rate compared to other components, with a downtime value of 27%.

3. Machines and Componen Downtime

The formula with the percentage value in equation (2) is used to determine which machine has more downtime. Therefore, the downtime percentage for Mixer Machine A Type B-15 is 44%, and for Mixer Machine B Type CS-20, it is 55%. Therefore, the total downtime for both mixer machines is 27.81 hours. Furthermore, the most critical machine condition can be identified by looking at the percentage of machine downtime that approaches 30%. So, the Mixer Machine B Type CS-20 is the most critical machine because its downtime approaches 100%, whereas Mixer Machine A Type B-15 has downtime below 50%. Therefore, it can be concluded that Mixer Machine B Type CS-20 has a higher criticality level of downtime, and further analysis will be conducted on the components that are the main causes of downtime.The downtime calculation for component failure is only taken from the Mixer Machine B Type CS-20 because it has the most significant downtime value. Then, the most critical component can be seen by using calculations for each component and the percentage of downtime for the component with the highest failure.

4. TTF and TTR

After identifying the component with the highest downtime level, the next step is to determine the bearing component's TTF and TTR.

Tabel 4. TTF and TTR for bearing component

No	Failure Start Time	Failure end time	TTR (Hour)	Failure end time - Working hours completed	Working hours begin - Failure Start Time	Working Hour (Hour)	TTF (Hour)
1	09:11	10:09	0,58	4,51	2,11		
2	14:18	15:08	0,50	5,22	1,18	1456	1461,6
3	10:29	11:20	0,51	3,40	3,29	608	616,51

Table 4 shows the results of TTR and TTF calculations for the bearing component based on data collected three times. It is known that for the second period, the TTR value is 0.50, and the TTF value is 1461.6. For the third period, the TTR value is 0.51, and the TTF value is 616.51.

The next step is to determine the distribution of the time interval between failures to be used. There are two distributions, namely exponential and Weibull. The Weibull distribution is crucial, especially in reliability and maintainability analysis (Maihulla, Yusuf, & Bala, 2023). The Weibull distribution is often used to understand the characteristics of the failure function (Li, Guan, Yuan, Yin, & Li, 2021) because changes in values result in the Weibull distribution having specific properties or equivalents to particular distributions, the Weibull distribution calculates the Mean Time Between Failure and the reliability of critical machines based on the Time Between Failure data. The exponential distribution is used to determine the optimal frequency of inspections for essential machines based on downtime data (Suryono & Rosyidi, 2018).

The distribution is selected based on the highest fit index value. Based on the least square curve fitting calculation for Time to Failure in the bearing component, the result shows that the exponential distribution has a fit index value of 0.99, which is higher than the Weibull distribution with a value of 0.97. Subsequently, a least square curve fitting calculation is also performed for Time to Repair, and the result shows that the Weibull distribution has a fit index value of -0.74, which is higher than the exponential distribution with a value of -0.57.

5. MTTF and MTTR

After deciding which distribution to use, the next step is calculating MTTF and MTTR. The time of failure uses an exponential distribution, and the repair time uses a Weibull distribution. Before calculating MTTF and MTTR, it is necessary to determine their parameters using the formula in Equation 3. Next, calculate the average time of failure or MTTF and the average time of repair or MTTR in the bearing component using the formula in equation 4. The results obtained are MTTF of 5.59 hours and MTTR of 2.29 hours.

Subsequently, the probability of system performance in fulfilling its function can be determined by calculating the reliability value of the bearing component before and after maintenance using the formula in Equation 5. The results are 0.31 before maintenance and 0.83 after maintenance. This proves that there is an improvement in system performance after maintenance.

6. Maintenance Time Interval

Based on the observations conducted on the bearing component, this component experienced the highest level of damage three times within one year. It is also known that there are 28 working days a month, with eight working hours per day for this bearing component. Thus, the average working hours per month amount to 224 hours. To determine the time interval for the bearing component, it is necessary to find the average repair time, average failure time, average failure rate, and optimal inspection frequency using the formulas in section 4. The results show that the reliability level of the bearing component before maintenance is 0.31 or 31%, while the reliability level of the bearing component after maintenance is 0.83 or 83%. Therefore, it is known that the value of the bearing component's failure time interval is 273.17 hours. Furthermore, it is proven that the maintenance activities carried out on the bearing component have a positive impact by increasing the reliability value.

CONCLUSIONS

Companies must optimize their assets to maintain highly competitive global competition. Machines and equipment are among the fundamental assets of manufacturing companies. Ensuring that machines and equipment operate optimally is, therefore, a priority. Maintenance is one strategy to ensure machine optimization. Hence, this research designs a maintenance system using the RCM and FMEA approaches.

Based on the results, it is known that the CS-20 Type B mixer machine has a higher critical downtime rate with a percentage of 55%. Apart from that, it is found that components in the CS-20 Type B mixer machine with the highest potential failure, compared to other components, with the highest downtime value of 27%, are the bearing components. The interval of bearing component failure is 273.17 hours, experiencing breakdowns three times with the highest damage within one year. This affects the machine's productivity level, requiring routine maintenance to address existing machine component damage and prevent further issues. After maintenance, the reliability of the bearing component increased to 83% from the previous 31%. Further research can provide more specific and scheduled machine and component maintenance procedures.

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