

# Determination of Preventive Maintenance Interval Based on Reliability Threshold and Risk-Based Maintenance

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## Abstrak

PT. XYZ adalah perusahaan produksi gula di mana mesin cane cutter berperan krusial dalam mencacah tebu sebelum proses ekstraksi. Selama masa giling (Mei–November 2023), mesin ini mengalami 31 kali kerusakan, yang memicu waktu henti (downtime) signifikan dan lonjakan biaya operasional. Penelitian ini bertujuan menentukan interval perawatan menggunakan pendekatan Risk-Based Maintenance (RBM) untuk menilai tingkat risiko, serta metode Cost of Unreliability (COUR) untuk mengukur dampak finansial. Analisis RBM awal mengidentifikasi nilai risiko bulanan sebesar Rp47.147.150. Melalui penerapan interval penggantian terjadwal—17 hari untuk pisau potong, 28 hari untuk piringan potong, 14 hari untuk bantalan (bearing), 31 hari untuk konveyor, dan 26 hari untuk turbin penggerak—Cost of Reliability (COR) ditetapkan sebesar Rp76.700.415/bulan. Meskipun estimasi pengeluaran meningkat, nilai tersebut masih berada dalam batas toleransi 2% perusahaan dengan tingkat keparahan 1,66%. Lebih lanjut, analisis COUR menunjukkan bahwa potensi kerugian akibat downtime sebesar Rp238.583.981 jauh melampaui biaya investasi pencegahan. Hasil penelitian ini membuktikan bahwa integrasi metode RBM dan COUR secara efektif mampu menyeimbangkan biaya perawatan, sekaligus melindungi perusahaan dari kerugian finansial yang tidak proporsional akibat ketidakandalan peralatan.

**Kata Kunci:** COUR, Perawatan, RBM, Risiko

## Abstract

PT. XYZ is a company engaged in sugar production, where the cane cutter machine plays a critical role in shredding sugarcane before extraction. During the milling period from May to November 2023, the machine experienced 31 breakdowns, leading to considerable downtime and increased operational costs. This study determines maintenance intervals using the Risk-Based Maintenance (RBM) approach to assess risk levels and the Cost of Unreliability (COUR) method to quantify financial impacts. The initial RBM analysis identified a monthly risk value of IDR 47,147,150. By implementing scheduled replacement intervals—17 days for the cutting knife, 28 days for the cutting disk, 14 days for the bearing, 31 days for the conveyor, and 26 days for the driving turbine—the Cost of Reliability (COR) was established at IDR 76,700,415/month. Although the planned expenditure increased, it remains within the company's 2% tolerance limit at a 1.66% severity level. Furthermore, the COUR analysis revealed that the potential downtime loss of IDR 238,583,981 far outweighs the preventive investment. These results demonstrate that integrating RBM and COUR methods effectively balances maintenance costs while protecting the company from disproportionate financial losses due to equipment unreliability.

**Keywords:** COUR, Maintenance, RBM, Risk

## 1. Introduction

Production is a crucial activity for a company, as it transforms inputs into outputs by adding value. In carrying out its production processes, the company heavily relies on machines and production facilities. Therefore, the most common step taken by companies to maintain the condition of these machines and facilities is through maintenance (Akbarizqi et al., 2022).

PT. XYZ, one of the sugar factories located in Malang, East Java, engaged in the production of white crystal sugar and derivative products such as sweet soy

sauce, molasses, and agricultural fertilizers. Based on failure data during the milling period from May to November 2023, the cane cutter machine experienced 31 breakdowns. This has led to the risk of downtime and increased costs of unreliability for the company.

Several previous studies have used Risk-Based Maintenance (RBM) to calculate risk values and determine the maintenance intervals, including those by Hartanto et al. (2023), Giffari & Prasetyawan (2021), and Aluna et al. (2018). The RBM method is used to prioritize maintenance activities based on the consequences and

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probability of component failure. This approach has proven effective in reducing system risks and improving operational efficiency (Khan & Haddara, 2003).

As a complement, the Cost of Unreliability (COUR) method is applied to calculate the total costs incurred due to machine unreliability, including both direct costs such as component replacement and labor, as well as indirect costs such as production losses (Salsabila et al., 2020). This method helps companies gain a more comprehensive and measurable understanding of the financial impact of machine failures.

Several previous studies, such as those by Bintarum et al. (2018) and Maharani et al. (2022), have employed a combination of these two methods to calculate risk values and evaluate the Cost of Unreliability (COUR)

caused by unplanned maintenance systems. This study aims to develop maintenance plans by identifying appropriate component replacement intervals to minimize the risk of failure and to reassess the risk value using the Risk-Based Maintenance (RBM) approach based on the proposed maintenance schedule. Furthermore, the cost of corrective maintenance due to component failures, based on the proposed replacement intervals, will be calculated using the Cost of Unreliability (COUR) method. By adopting these two methodological approaches, the company is expected to improve the reliability of its production equipment and significantly reduce losses caused by unexpected breakdowns.

## 2. Research Methods

The steps of this research are shown in the flowchart in Figure 1.

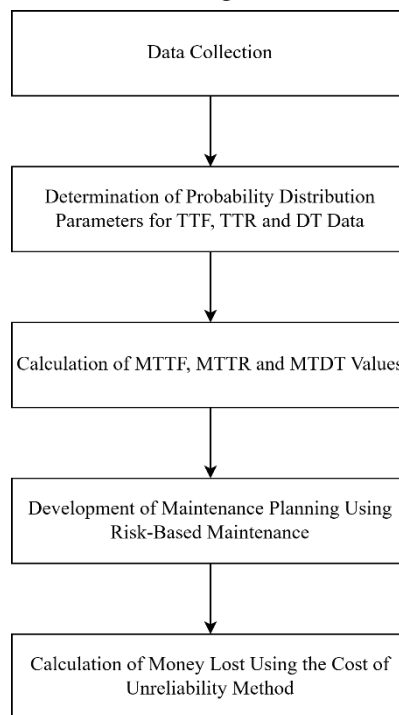


Figure 1: Research Methods

### 2.1. Data Collection

This study uses both primary and secondary data. Primary data were obtained through direct observation of production and maintenance activities, as well as interviews with the installation team regarding machine operation, repair time, and causes of failures. Secondary data were collected from company records. This dataset includes machine failure history, cost parameters (component, labor, and production loss), and operational metrics such as time to failure (TTF), time to repair (TTR), and downtime (DT), all of which are relevant for both the RBM and COUR methods.

### 2.2. Determination of Probability Distribution Parameters for TTF, TTR, and DT Data

Distribution fitting was performed using the Anderson-Darling method to determine the most appropriate probability distribution for each machine component. The analysis was conducted on three types of data: time to failure (TTF), time to repair (TTR), and downtime (DT).

### 2.3. Determination of Mean Time to Failure (MTTF), Mean Time to Repair (MTTR), and Mean Downtime (MTDT)

The expected values for time-to-failure, time-to-repair, and downtime were determined by calculating the

mean of the selected probability distribution for each machine component. It is important to note that TTF, TTR, and DT are distinct random variables that may follow different distributions (e.g., Weibull for TTF and Lognormal for TTR). Therefore, the parameters for each variable were estimated independently before calculating the mean. The mean value ( $\mu$ ) for each distribution is calculated using the following equations:

a. Normal Distribution (1)

$$\mu = \text{mean of distribution}$$

b. Lognormal Distribution (2)

$$\mu = \exp\left(\theta + \frac{s^2}{2}\right)$$

c. Exponential Distribution (3)

$$\mu = \frac{1}{\lambda}$$

d. Weibull Distribution (4)

$$\mu = \theta \times \Gamma\left(\frac{1}{\beta}\right) + 1$$

where:

- $\mu$  = mean value of the distribution (days).
- $s$  = standard deviation of the log-transformed data.
- $\lambda$  = failure rate (failures/day).
- $\theta$  = scale parameter (for Weibull) or location parameter (for Lognormal).
- $\Gamma$  = gamma function.
- $\beta$  = shape parameter.

*System performance loss (SPL)*

$$\begin{aligned} &= (MTDT \times \text{loss revenue}) \\ &+ (MTTR \times \text{labor rate}) + \text{material cost} \\ &+ \text{component cost} \end{aligned} \quad (5)$$

### 3. Probability of Failure

The probability of failure analysis can be obtained using failure and reliability data, as well as through Fault Tree Analysis (FTA). The calculation of the failure probability value is performed using the equation (6) function (Ebell, 1997).

$$Q(t) = 1 - R(t) \quad (6)$$

where:

Q(t) = probability of failure

R(t) = reliability value

### 4. Risk Estimation

Risk estimation is performed by considering the results of the consequence analysis with the probability of failure. The risk value is obtained using the equation (7) function.

$$\text{Risk} = \text{SPL} \times Q(t) \quad (7)$$

## 2.4. Development of Maintenance Planning Using Risk-Based Maintenance

The risk estimation module is the initial stage of the RBM framework, aimed at quantifying the probability and consequences of potential equipment failures. This process begins by identifying how components fail and the impact these failures have on the system. The following steps describe the detailed procedure for estimating risk.

### a. Risk Estimation

#### 1. Development of Failure Scenarios

The development of failure scenarios is obtained from historical component failure data recorded by the company, as well as interviews with workers.

#### 2. Consequence Analysis

The consequence analysis is conducted in two stages. The first stage is to perform the consequence analysis, which involves quantifying the scenarios in numerical form by assigning a value from 1 to 10 based on the impact of the failure scenario. Next, the risk consequence value is calculated, where the consequence analysis factor in this study is system performance loss. According to (Bintarum et al., 2018), the calculation of system performance loss (SPL) is performed using equation (5).

### b. Risk Evaluation

1. Prepare the acceptance criteria that have been determined by the company.

2. Compare the risk with the acceptance criteria. The risk value obtained from the calculation is compared with the acceptance criteria. If the risk percentage is below the acceptance criteria, maintenance planning is then carried out.

### c. Maintenance Planning

This step involved developing a proposed maintenance schedule by identifying suitable replacement intervals for machine components, with the goal of reducing the failure risk level. After the proposed interval was established, the risk value was recalculated accordingly.

## 2.5. Calculation of Money Lost Using the Cost of Unreliability (COUR) Method

In this study, the Cost of Unreliability (COUR) is prioritized over the Cost of Reliability (COR) due to the nature of the sugar production process, where the financial impact of unplanned downtime is significantly

more catastrophic than the direct costs of preventive activities. While COR (preventive costs) is a standard consideration in maintenance, this framework focuses on COUR to highlight the 'hidden costs' and production losses that directly erode company profitability. This approach aligns with the Risk-Based Maintenance (RBM) framework proposed by Khan & Haddara (2003), which emphasizes a consequence-driven strategy to minimize overall operational risk.

To quantify the financial impact of equipment failures, the COUR method follows a structured calculation process that integrates reliability data with economic consequences. The following steps outline the systematic approach used by Maharani et al. (2022):

a. Failure Rate

The first stage of the COUR method calculation is to determine the failure rate of each component. Since the machine components follow different probability distributions, such as Normal, Lognormal, and Weibull, their failure rates are time-dependent. However, to quantify the total economic impact over the specific observation period, the

$$\begin{aligned} & \text{Corrective time lost} \\ & = \text{MTTR} \times \text{Number of Failures in the Observation Period} \end{aligned} \quad (9)$$

$$\begin{aligned} & \text{Downtime time lost} \\ & = \text{MTDT} \times n \text{Number of Failures in the Observation Period} \end{aligned} \quad (10)$$

c. Calculation of Money Lost

The final stage in the COUR method calculation involves calculating the total money lost. This includes both corrective money lost and downtime money lost. The calculation of corrective money lost is carried out using equations (11) to (14), while the downtime money lost is determined using equations (15) to (18).

The variables in Equations (1) through (18) are defined with their respective units to ensure dimensional consistency. Time-based variables, such as MTDT, MTTR, corrective time lost, and

$$\text{Production loss cost} = \text{corrective time lost} \times \text{loss of revenue} \quad (11)$$

$$\text{Component cost} = \text{corrective time lost} \times \text{component price} \quad (12)$$

$$\text{Labor cost} = \text{corrective time lost} \times \text{labor rate} \quad (13)$$

$$\text{Corrective money lost} = \text{production loss cost} + \text{component cost} + \text{labor cost} \quad (14)$$

$$\text{Production loss cost} = \text{downtime time lost} \times \text{loss of revenue} \quad (15)$$

$$\text{Component cost} = \text{downtime time lost} \times \text{component price} \quad (16)$$

$$\text{Labor cost} = \text{downtime time lost} \times \text{labor rate} \quad (17)$$

$$\text{Downtime money lost} = \text{production loss cost} + \text{component cost} + \text{labor cost} \quad (18)$$

Equations (12) and (16) incorporate the time-lost variable to quantify the cumulative financial impact of component replacements over the entire 6-month observation period. This approach does not imply that the unit price of a component changes based on the repair duration; rather, it is used to

Average Failure Rate ( $\lambda_{avg}$ ) is employed. This value represents the frequency of failures relative to the total operating time during the study period. The average failure rate is calculated using Equation (8):

$$\lambda_{avg} = \frac{n}{T} \quad (8)$$

where:

$\lambda_{avg}$  = average failure rate (failures/day)

n = total number of failures during the observation period (failures)

T = total observation or operating time (days)

b. Time Lost

The parameters used include the failure rate and the number of failures recorded during the study. This is followed by determining the MTTR and MTDT for each failure event. The total Corrective Lost Time over the 6-month observation period is then calculated using Equation (9), while the total Downtime for the same period is derived from Equation (10).

downtime lost, are measured in days. Cost-related parameters, including labor rate and loss of revenue, are expressed in IDR/day. Other parameters evaluated include labor cost, material cost, component cost, system performance loss (SPL), production loss cost, and downtime money lost are measured in IDR. By defining these units, the total financial risk and unreliability costs can be validated as the product of time and daily cost rates. Detailed values and specific units for each parameter are further specified in the Results section (Tables 6, 13, 14, and 15).

represent the frequency-weighted material loss relative to the total downtime experienced during the milling season. By integrating time into these equations, the COUR method can effectively capture the total economic risk of unreliability for the system.

The labor cost in Equation (13) and (17) is calculated by multiplying the repair duration with a standardized labor rate of IDR 133,333/day. This rate is derived from the average monthly wage for maintenance technicians at the facility (IDR 4,000,000) divided by 30 working days. Using this specific rate ensures that the financial model reflects the direct labor expenditure associated with each failure event under actual field conditions.

### 3. Result and Discussion

#### 3.1. Data Collection and System Identification

The data collection process was conducted at the Milling Station of PG. Kreet Baru I during the 2023 milling season, spanning from May to November (a 6-month time horizon). Based on the failure records at the station, the cane cutter machine was identified as the most critical unit, experiencing the highest failure frequency with 31 breakdown incidents during the observation period. The system structure of the cane cutter machine was analyzed by identifying its primary components to provide a comprehensive understanding of the failure points. The machine consists of five critical components: the cutting knife, cutting disc, bearing, conveyor, and driving turbine. A summary of the failure incidents for each component over the 6-month horizon is presented in Table 1.

**Table 1:** Summary of Failure Incidents for Cane Cutter Components

No	Component	Number of Failures	Dominant Failure Mode
1	Cutting Knife	8	Wear/Blunt, Cracks
2	Cutting Disc	6	Corrosion, Wear
3	Bearing	8	Broken, Lubricant Dry-out
4	Conveyor	5	Stretching, Clogging
5	Driving Turbine	4	Overheat
<b>Total</b>		<b>31</b>	

The historical data in Table 1 indicates that the cutting knife and bearing are the components with the highest failure rates. These failure datasets, which include time to failure (TTF), time to repair (TTR), and downtime (DT), serve as the fundamental basis for the reliability distribution analysis and the subsequent risk quantification.

#### 3.2. Probability Distribution Parameter Results for TTF, TTR, and DT Data

The failure-related data utilized in this study include time to failure (TTF), time to repair (TTR), and downtime (DT). TTF refers to the operational interval from the completion of a repair to the occurrence of the next failure. TTR represents the duration required to restore the machine to an operational state after a failure, while DT indicates the total period during which the machine is non-operational. The following presents the calculation results for TTF, TTR, and DT in the Table 2.

**Table 2:** Distribution Parameters for TTF, TTR, and DT Data

No	Components	Distribution								
		TTF	Parostameter	TTR	Parameter	DT	Parameter			
1	Cutting Knife	Normal	$\mu$	28.714	Weibull	$\beta$	6.609	Lognormal	S	0.088
						$\Theta$	0.034		Tmed	0.045
2	Cutting Disc	Lognormal	S	0.264	Lognormal	S	0.402	Lognormal	S	0.225
			Tmed	35.427		Tmed	0.039		Tmed	0.058
3	Bearing	Normal	$\mu$	28.428	Normal	$\mu$	0.03	Weibull	$\beta$	7.344
									$\Theta$	0.049
4	Conveyor	Normal	$\mu$	44	Lognormal	S	0.255	Lognormal	S	0.264
						Tmed	0.027		Tmed	0.04
5	Driving Turbine	Weibull	$\beta$	2.969	Lognormal	S	0.144	Weibull	$\beta$	25.6
			$\Theta$	44.647		Tmed	0.044		$\Theta$	0.063

Table 2 shows the results of the distribution parameter estimations for the TTF, TTR, and DT datasets. These parameters will be utilized in the subsequent calculation of MTF, MTTR, and MTDT values.

#### 3.3. Results of MTF, MTTR, and MTDT Calculation

MTF, MTTR, and MTDT values were calculated based on the selected distribution for each component.

**Table 3:** Result of MTTF, MTTR and MTDT

No	Components	MTTF (day)	MTDT (day)	MTTR (day)
1	Cutting Knife	29	0.045	0.032
2	Cutting Disc	37	0.059	0.042
3	Bearing	28	0.046	0.030
4	Conveyor	44	0.041	0.028
5	Driving Turbine	40	0.062	0.044

Table 3 presents these values, which will be used to calculate reliability, probability of failure, and component replacement intervals for the cane cutter machine.

### 3.4. Results of Maintenance Planning Using Risk-Based Maintenance

**Table 4:** Failures Scenario

No	Component	Failures Scenario	Effect
1	Cutting Knife	1 Dull knife	The knife cannot cut the sugarcane quickly and slows down the cutting process
		2 Cracked knife	The machine must be turned off for blade replacement, which causes downtime
		3 Jammed knife	The accumulation of sugarcane on the conveyor, which slows down the cutting process
2	Cutting Disc	4 Corrosion	The surface of the disc becomes uneven and slows down the cutting process
		5 Dull disc	A decrease in cutting efficiency, causing the sugarcane to not be cut quickly
		6 Lubricant dries	The rotation of the cutting knife becomes obstructed
		7 Broken bearing	The bearing is unusable, so component replacement is required
3	Bearing	8 Lubricant dries	The rotation of the bearing is obstructed
		9 Dull bearing	Excessive vibration occurs, causing components such as the cutting disc to wear out
4	Conveyor	10 Delayed conveyor	The rotation is incorrect, causing the sugarcane to go off track
		11 Jammed conveyor	There is an accumulation of sugarcane, which causes the production process to be delayed
5	Driving Turbine	12 Overheat	The machine is turned off for repair

#### 2. Consequence Analysis

According to Khan & Haddara (2003), risk consequence analysis is carried out in two stages. The first stage involves quantifying failure scenarios on a scale from 1 to 10 to identify components with the highest impact on the system, which serves as a basis for further

#### a. Risk Estimation

The risk estimation in RBM calculations consists of four stages, namely:

##### 1. Development of Failures Scenario

The first step in the RBM calculation is to develop failure scenarios for machine components. These scenarios were created using historical maintenance data from the milling period of May to November 2023, along with interviews with the head of the installation department and milling station operators. Table 4 shows the developed failure scenarios for the cane cutter machine components. After identifying these scenarios, the next step is to assess the consequences of each failure.

calculations. The results of this analysis are shown in Table 5. Table 5 highlights three components with high consequence scores: the cutting knife, bearing, and drive turbine, with values of 9 and 10. Following this, the failure probabilities of these components are calculated.

**Table 5:** Consequence Analysis

No	Component	Failures Scenario	Consequence Analysis	Description	
1	Cutting Knife	1	Dull knife	7	A malfunction in the machine's performance occurs, which slows down the cutting process
		2	Cracked knife	9	The damage caused the machine to be shut down for component replacement
		3	Jammed knife	6	The damage causes the machine's performance to be suboptimal
		4	Corrosion	7	The damage causes the machine's performance to be suboptimal
2	Cutting Disc	5	Dull disc	7	The damage slows down the cutting process
		6	Lubricant dries	6	The damage slows down the machine's performance
		7	Broken bearing	10	The damage requires the machine to be shut down for component replacement
3	Bearing	8	Lubricant dries	6	The damage slows down the machine's performance
		9	Dull bearing	7	The damage slows down the cutting process
		10	Delayed conveyor	8	The damage requires the machine to be shut down for repairs
4	Conveyor	11	Jammed conveyor	7	Decreased machine performance that slows down the sugarcane cutting process
		12	Overheat	9	The damage requires the machine to be shut down for inspection

The qualitative assessment in Table 4 and Table 5 serves as a foundational screening tool to prioritize maintenance activities. The consequence analysis (Table 5) identifies high-impact scenarios—specifically for the bearing (10), cutting knife (9), and driving turbine (9)—where failure leads to immediate machine shutdowns. These scores directly justify the allocation of resources and provide an operational context for the quantitative Risk estimation in the following sections. By identifying these critical scenarios, the study ensures that the calculated maintenance intervals focus on mitigating the most severe operational disruptions.

### 3. Probability of Failure Analysis

The initial step in performing RBM calculations is to develop failure scenarios for machine components. These scenarios are based

on historical maintenance data from the milling period between May and November 2023, as well as interviews with the head of the installation department and milling station operators. The process includes:

- a. Using time to failure (TTF) data that has been tested for distribution.
- b. Calculating the reliability value  $R(t)$ .
- c. Setting  $t$  equal to the mean time to failure (MTTF), as the factory's maintenance system does not implement preventive maintenance.
- d. Calculating the probability of failure  $Q(t)$ .

Table 6 presents the results of the failure probability calculations for each component. These values will be used to assess system performance loss. Components with reliability below 50% will undergo cost evaluation using the Cost of Unreliability method.

**Table 6:** Probability of Failure

No	Component	MTTF (day)	$R(t)$	$Q(t)$
1	Cutting Knife	29	0.500	0.500
2	Cutting Disc	37	0.447	0.553
3	Bearing	28	0.500	0.500
4	Conveyor	44	0.500	0.500
5	Driving Turbine	40	0.070	0.930

#### 4. System Performance Loss

After determining the failure probabilities, the next step is to calculate the risk consequence values representing potential losses to the company due to system performance loss. This

calculation uses data such as MTDT, MTTR, revenue loss, labor costs, consumable material costs, and component prices. The results of the system performance loss calculations are presented in Table 7.

**Table 7:** System Performance Loss

No	Component	MTDT (day)	MTTR (day)	Loss of Revenue (IDR/day)	Labor Rate (IDR/day)	Material Cost (IDR)	Component Cost (IDR)	System Performance Loss (IDR)
1	Cutting Knife	0.045	0.032	153,600,000	133,333	1,023,333	600,000	8,539,599
2	Cutting Disc	0.059	0.042	153,600,000	133,333	1,511,666	900,000	11,479,665
3	Bearing	0.046	0.03	153,600,000	133,333	3,116,666	500,000	10,686,265
4	Conveyor	0.041	0.028	153,600,000	133,333	523,333	423,000	7,247,666
5	Driving Turbine	0.062	0.044	153,600,000	133,333	46,666	7,250,000	16,825,732

#### 5. Risk Estimation

Risk estimation is performed by integrating the results of the consequence analysis with the failure frequency, adapted from the framework by Khan (2003) and Dhamayanti et al (2016). While the original model often utilizes a single-event probability ( $Q(t)$ ), this study modifies Equation (7) to align with a monthly operational cost analysis. The risk value is obtained by replacing the probability with the expected number of failures per month ( $E[n]$ ), as follows:

$$\text{Risk/Month} = E[n] \times \text{SPL}$$

where:

$E[n]$  = expected number of failures per month (failures/month).

$\text{SPL}$  = system performance loss per failure event (IDR).

The value of  $E[n]$  is derived from the average failure rate ( $\lambda_{\text{avg}}$ ) of each component. For example, the Cutting Knife has an MTTF of 29 days. Thus, its expected monthly failure is:

$$E[n] = \frac{1}{29} \times 30 = 1.034 \text{ failure/month}$$

The result of this calculation,  $1.034 \times \text{IDR } 8,539,599$ , yields a monthly risk of IDR 8,829,945 for this component. The complete results for all components are presented in Table 8.

**Table 8:** Risk Values

No	Component	$E[n]$ (Failures/Month)	System Performance Loss (IDR)	Risk/month (IDR)
1	Cutting Knife	1.034	8,539,599	8,829,945
2	Cutting Disc	0.811	11,479,665	9,310,008
3	Bearing	1.071	10,686,265	11,444,990
4	Conveyor	0.682	7,247,666	4,942,908
5	Driving Turbine	0.750	16,825,732	12,619,299
Total				47,147,150

#### b. Risk Evaluation

##### 1. Prepare the acceptance criteria

The acceptance criteria were established through direct interviews with the head of the installation department. The company set a

machine failure risk tolerance limit at 2%, with reliability values for each component  $\geq 80\%$ .

2. Compare risk value against acceptance criteria

The risk values obtained from the risk estimation calculations are compared with the acceptance criteria set by the company. If the risk value exceeds the acceptance criteria,

maintenance planning must be conducted by calculating the effective maintenance intervals for each component. The comparison results are shown in Table 9.

**Table 9:** Comparison Results Risk Values Against Acceptance Criteria

Income/day (IDR)	Income/month (IDR)	Risk Total/month (IDR)	Percentage	Tolerance Limit
153,600,000	4,608,000,000	47,147,150	1.02%	2%

Table 9 shows the percentage of risk values that are rejected or exceed the tolerance limit. These results will be used to improve the maintenance planning to achieve risk percentages below the company's tolerance limit.

c. Maintenance Planning

The maintenance proposal involves determining scheduled component replacement intervals ( $t$ ) based on a predefined reliability threshold. These intervals are established apriori to ensure that each component maintains a reliability level of at least 80%, satisfying the company's internal operational requirements.

**Table 10:** Scheduled Maintenance Intervals Based on Reliability Threshold

No	Component	Distribution	Parameter	$R(t)$	$Q(t)$	$t$ (day)
1	Cutting Knife	Normal	$\mu$ 28.714 $\sigma$ 13.306	0.8107	0.1893	17
2	Cutting Disk	Lognormal	S 0.264 $\theta$ 35.427	0.8136	0.1864	28
3	Bearing	Normal	$\mu$ 28.428 $\sigma$ 16.421	0.8102	0.1898	14
4	Conveyor	Normal	$\mu$ 44 $\sigma$ 15.116	0.8051	0.1949	31
5	Driving Turbine	Weibull	$\beta$ 2.969 $\theta$ 44.647	0.8181	0.1819	26

Table 10 presents the proposed replacement intervals: cutting knife every 17 days, cutting disk every 28 days, bearing every 14 days, conveyor every 31 days, and driving turbine every 26 days. These intervals represent a shift toward a planned maintenance strategy, where components are replaced before the expected failure occurs.

To evaluate the economic impact of this planning, the risk is recalculated by determining the expected frequency of maintenance events per month ( $E[n]_{plan}$ ) based on these intervals. The risk value is the product of this frequency and the system performance loss (SPL), as summarized in Table 11.

**Table 11:** Results of Risk Value after Maintenance Planning

No	Component	$t$ (day)	$E[n]_{plan}$ (events/month)	System Performance Loss (IDR)	Risk/month (IDR)
1	Cutting Knife	17	1.765	8,539,599	1,616,833
2	Cutting Disc	28	1.071	11,479,665	2,140,017
3	Bearing	14	2.143	10,686,265	2,028,260
4	Conveyor	31	0.968	7,247,666	1,412,498
5	Driving Turbine	26	1.154	16,825,732	3,061,092
Total					76,700,415

Table 11 shows that the total monthly planned risk amounts to IDR 76,700,415. Although this value is higher than the initial unplanned risk, it represents a controlled and predictable expenditure aimed at preventing catastrophic system downtime.

The recalculated risk is then compared against the company's acceptance criteria to ensure economic feasibility. As presented in Table 12, despite the increase in planned maintenance frequency, the total risk percentage remains well within the company's tolerance.

**Table 12:** Results of Risk Values Against Acceptance Criteria

Income/month (IDR)	Risk Total/month (IDR)	Percentage	Tolerance Limit
4,608,000,000	76,700,415	1.66%	2%

### 3.5. Cost of Unreliability

#### a. Failure Parameters and Time Lost Analysis

The assessment of unreliability costs begins with an analysis of failure parameters and the resulting time lost due to equipment breakdowns.

Table 13 summarizes the operational data over the 6-month milling period, including the average failure rate, mean time to repair (MTTR), and mean time delay (MTDT) for each critical component.

**Table 13:** Recapitulation of Failure Parameters and Time Lost (6-Month Period)

Parameter	Cutting Knife	Cutting Disc	Bearing	Conveyor	Driving Turbine
Observation Time (hours)	4368	4368	4368	4368	4368
Number of Failures	8	6	8	5	4
MTTF (day)	29	37	28	44	40
Avg. Failure Rate (per day)	0.035	0.027	0.035	0.023	0.025
MTTR (day)	0.032	0.042	0.030	0.028	0.044
MTDT (day)	0.045	0.059	0.046	0.041	0.062
Corrective Time Lost (day)	0.256	0.252	0.240	0.140	0.176
Downtime Time Lost (day)	0.360	0.354	0.368	0.205	0.248

Based on the recapitulation in Table 13, the time lost is categorized into corrective time lost—reflecting active repair time—and downtime time lost, which includes both repair time and logistical delays. These values serve as the primary input for the financial loss estimation in the subsequent Cost of Unreliability (COUR) analysis.

#### b. Money Lost and Cost Overview Analysis

The final stage of the COUR method evaluates the financial impact of equipment failures by comparing corrective money lost (active repair costs) and downtime money lost (total stoppage costs). Table 14 summarizes these financial losses for each component, along with the total Cost of Unreliability (COUR) for the system.

**Table 14:** Financial Risk and Cost of Unreliability (COUR) Summary

Component	Corrective Money Lost (IDR)	Downtime Money Lost (IDR)	COUR Difference (IDR)
Cutting Knife	39,509,333	55,560,000	16,050,667
Cutting Disc	38,967,600	54,740,200	15,772,600
Bearing	37,016,000	56,757,867	19,741,867
Conveyor	21,581,887	31,602,048	10,020,161
Driving Turbine	28,333,067	39,923,867	11,590,800
Total (System)	165,407,886	238,583,981	73,176,095

As shown in Table 14, the total downtime COUR of IDR 238,583,981 significantly exceeds the corrective COUR of IDR 165,407,886, resulting in a maintenance cost difference of IDR 73,176,095. This indicates substantial financial losses due to unreliability, largely driven by a potential production loss of IDR 153,600,000 per day during mill stoppages. According to components (Alhilman, 2017), when downtime costs exceed corrective costs, it confirms that the current equipment unreliability is causing direct economic losses to the company.

### 3.6. Economic Trade-off Analysis

The proposed maintenance intervals, while more frequent than the existing schedule, are designed to transform the nature of operational risk. In this analysis, the monthly risk is quantified as an expected frequency of events ( $E[n]$ ) derived from the target-based replacement intervals. Based on this approach, the monthly planned risk (Cost of Reliability/COR) is IDR 76,700,415, which is an increase from the initial unplanned risk of IDR 47,147,150.

To justify this strategy, a trade-off analysis must be performed between the increased procurement and maintenance costs and the consequences of failure. The

monthly expenditure increase of IDR 29,553,265 (the difference between planned and initial risk) is effectively a "reliability premium". In the sugar milling industry, the potential loss of revenue due to unplanned downtime is estimated at IDR 153,600,000 per day.

Comparing these figures, the additional monthly cost for more frequent component replacements is equivalent to only 19.2% of a single day's production loss. Therefore, the 'preventive-heavy' strategy is not an instance of inefficient over-maintenance, but a calculated economic trade-off. By accepting a higher scheduled maintenance cost, the company mitigates the risk of catastrophic financial losses that could exceed IDR 150 million from just 24 hours of unplanned downtime. This strategy ensures that the total risk of IDR 76,700,415 per month remains well within the company's 2% tolerance limit.

#### 4. Conclusion

This study recommends revising the current component replacement intervals to optimize the balance between reliability and total maintenance expenditure. The proposed scheduled replacement intervals are 17 days for the cutting knife, 28 days for the cutting disk, 14 days for the bearing, 31 days for the conveyor, and 26 days for the driving turbine. By implementing these intervals, the overall cost analysis considers both the Cost of Unreliability (COUR) and the Cost of Reliability (COR). While the monthly preventive investment (COR) is established at IDR 76,700,415/month, it is strategically justified by the significant reduction in unplanned failure consequences. The COUR analysis reveals that the potential downtime loss of IDR 238,583,981 far outweighs the planned maintenance costs. Therefore, the integrated use of COUR and COR demonstrates that the proposed strategy provides a robust economic cushion, maintaining total risk at 1.66%—well within the company's 2.00% acceptance limit. Future studies are encouraged to explore the integration of predictive maintenance approaches using real-time monitoring technologies, such as condition-based monitoring (CBM) or Internet of Things (IoT)-based systems. These methods could enhance the accuracy of failure prediction and optimize maintenance scheduling, further improving reliability and reducing total maintenance costs.

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