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OPTIMIZATION OF DETERMINING MAINTENANCE INTERVALS WITH THE MARKOV CHAIN METHOD TO MINIMIZE MAINTENANCE COSTS IN PT. BBI

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ABSTRACT

PT BBI is a company engaged in producing machinery, industrial equipment, and foundry. PT BBI has overgrown as a company that focuses on manufacturing and delivering products such as oil and gas/refinery/petrochemical industries, power plans, iron castings, precision machinery centers, etc. PT BBI uses various kinds of machines to support its production process. Some devices have often experienced damage and caused downtime in recent years, namely radial drilling machines and overhead cranes. In addition, machine damage also causes cost overruns due to damage that can harm the company. Engine damage caused is due to the company's poor maintenance policy. Judging from these problems, planning a maintenance system with a suitable method will help the machines and production equipment owned by PT. BBI is protected from damage that occurs periodically. The Markov Chain method was chosen because it has advantages over other maintenance methods because it produces more optimal maintenance costs with a regular maintenance scheduling system. The processing results obtained a total savings of 33% by applying the Markov Chain proposed maintenance method with maintenance intervals every 5 months for radial drilling machines and once every 3 months for 10T overhead cranes.

Keywords: Markov Chain, Maintenance, Maintenance Cost

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1. INTRODUCTIONTION

Industrial competition in the modern world is getting stricter, and the development of increasingly sophisticated technology makes every company refuse to get urged to maximize its resources, which is the machine. In today's fully automated world, the need for human labor is starting to be replaced by sophisticated machines or equipment. The efficiency and productivity of a device should be visible from the state of the engine and the gear that upholds it (Purnomo, 2015). Continuous use of the machine will affect the decline in the quality and performance of the engine, and if there is damage, it will cause losses. Damage to factory machines will hinder the production process, so the company's productivity will decrease. In addition, damage to the factory machine will also cause repair costs that are not cheap. Human error, an emergency, a lack of maintenance, and other factors can cause machine failure (Candra, 2020). To avoid these losses, maintenance (maintenance) on factory machines plays an important role. Machine maintenance includes corrective, namely maintenance activities after the engine is damaged, and preventive, namely machine maintenance activities to prevent damage (Arsyadiaga, 2018).

PT. BBI, located in East Java, is a company engaged in producing machinery, industrial equipment, and foundry. PT. BBI has developed quickly as an organization that focuses on manufacturing and delivering products such as oil & gas/refinery/petrochemical industry, power plan, iron casting, precision machinery center, etc. PT. BBI uses various machines to support its production process. In the last few years, some devices have been damaged several times and caused downtime, namely radial drilling machines and overhead cranes.

So far, PT. BBI performs machine maintenance activities only when the machine has problems or is damaged because this method is considered more practical. So, this company applies corrective maintenance methods where corrective actions or new maintenance are carried out when an engine failure occurs. If there is a mechanical failure when the machine is operating, the production process must be stopped while repairs are carried out. This condition is hazardous to the timeliness of completing orders from customers. Machine failure also causes cost overruns due to damage that can be detrimental to the company.

Markov Chain is a method that studies variable events in the present, which is based on past events to predict the events of the same variable in the future (Ariyani, 2010). Markov Chain has advantages namely simple and practical calculations because it is formulated in a probability matrix - transitional probability, where the current state is independent of the past state. So the current process does not depend on the length of the process that occurred in the past, but the calculation is based on the current state.

During operation, a system will go through various possible state transitions. If a new item is repaired after a highly damaged item, statuses 2 and 3 are ignored. However, if the maintenance policy is modified and in status 2, 3, or 4, it can also be converted to status 1 (Bagaskara Adi Pamungkas, 2020). The status and condition of the machine can be classified as follows:

1. Status 1 indicates good condition
2. Status two indicates a slightly damaged condition
3. Status three indicates a moderately damaged condition
4. Status four indicates a heavily damaged condition.

A previous study (Hartono and Ilyas, 2002) stated that the decisions taken in determining maintenance could be written as follows:

1. Decision 1 is not to take action
2. Decision 2 is to carry out preventive maintenance (system returns to the previous status)
3. Decision 3 is to perform corrective maintenance (system returns to state 1)

If an item is in light damage and moderate damage status, then the item will not experience a transition to a good state. In other words, an item in the light damage and moderate damage status will remain in the light damage and moderate damage status or will only switch to the heavy state. And if the item is in severe damage status or other words, an item that is deteriorating will continue to decline until the next inspection interval. Otherwise, the item will suffer severe damage as long as the interval is repaired at the next inspection interval (Kusuma, 2018).

In engine maintenance management, Markov Chain can analyze future engine state transitions from good condition, light damage, and moderate damage (Ramadhan et al., 2020). Markov Chain has advantages compared to other machine maintenance methods. More optimal maintenance costs will be obtained, and a regular scheduling system for machine maintenance can be known (Maulana, 2019). Thus, the Markov Chain method was chosen to solve these problems to reduce maintenance costs through planning regular and regular machine maintenance activities so that it can increase efficiency by reducing damage to production machines.

2. METHODS

The research method used in this study is a descriptive method to describe the data being researched to get a complete picture of the data either in the verbal or numerical form related to the data being studied to obtain better results than before. In addition, this research also applies an analytical study by managing the data obtained from the company.

The data needed in this study were obtained from the maintenance division of PT. BBI, The data are:

a. Data type and the quantity of machines
b. Machine state transition data
c. Maintenance time data
d. Downtime cost data

Data collection is done by making direct observations, commonly called field studies, in the machining and maintenance section to obtain primary data from the observed object. Secondary data were obtained from literature and company data.

In this study, data processing is carried out using the Markov Chain Method, which is used to analyze the possibility of transitioning machine status from good condition, lightly damaged, moderately damaged, to heavily damaged in the future (Anastasia, 2021). Markov chains have the unique property that probabilities relating to how the process will evolve in the future are only reliant on the current state of the process and so are unaffected by past events (Hillier and Liberman, 2001). The steps for solving the problem using the Markov Chain method are:

1. Calculating the transition probability of machine status
2. Forming initial and recommended transition matrices
3. Calculating the probability of steady-state machine status
4. Calculating maintenance costs
   C_{1i} = Preventive maintenance time per year × downtime cost
   C_{2i} = Corrective maintenance time per year × downtime cost
6. Calculating average expected maintenance cost
   $$E = \sum_{j=1}^{m} \pi_j C_j \quad (1)$$
   Description :
   E = the expected average cost
   π_j = probability of steady state status in the long term (steady state)
   C_j = corrective maintenance costs for each item j
7. Calculating maintenance cost savings
8. Determining optimal machine maintenance intervals

3. FINDINGS AND DISCUSSION

The research focuses on the machines that experience downtime at PT BBI, namely 7 units of radial drilling machines and 5 units of overhead crane 10T machines. Machine status transition data are presented in Table 3 (pages 4) for radial drilling machines and Table 2 (pages 4 and 5) for overhead cranes 10T.

The machine maintenance time, which consists of preventive maintenance and corrective maintenance, is as follows.

Table 1. Total Maintenance Time

Machines	Preventive (Hours/Year)	Corrective (Hours/Year)
Radial Drilling	35	120
Overhead Crane 10T	30	73,5

Corrective maintenance time data were obtained from the machine downtime in 2021. Downtime costs are costs that arise as a result of non-operation a machine (Candra, 2020). Downtime costs are caused by the unplanned cessation of production activities due to engine damage or repair problems. Downtime cost data is shown in the table below.

Table 2. Downtime Cost Data

No	Machine	Downtime Cost (Rp)
1	Radial Drilling	1.235.500
2	Overhead Crane 10T	1.625.000

Table 3. Radial Drilling Machine Status Transition on January - December 2021

Months	Weeks	Status									
		p_{11}	p_{12}	p_{13}	p_{14}	p_{22}	p_{23}	p_{24}	p_{33}	p_{34}	p_{41}
January	**1-2**	4	0	0	0	1	0	0	0	2	0
	2-3	4	0	0	0	0	0	1	0	0	2
	3-4	3	2	1	0	0	0	0	0	0	1
	4-1	4	0	0	0	2	0	0	1	0	0
February	**1-2**	2	0	1	0	2	0	1	0	1	0
	2-3	2	1	0	0	0	1	0	1	0	2
	3-4	4	0	0	0	1	0	0	0	2	0
	4-1	3	0	1	0	0	1	0	0	0	2
March	**1-2**	5	0	0	0	0	0	0	2	0	0
	2-3	4	0	1	0	0	0	0	0	2	0
	3-4	4	0	0	0	0	0	0	0	1	2
	4-1	5	1	0	0	0	0	0	0	0	1
April	**1-2**	5	0	1	0	0	1	0	0	0	0
	2-3	5	0	0	0	0	0	0	2	0	0
	3-4	5	0	0	0	0	0	0	2	0	0
	4-1	4	1	0	0	0	0	0	1	1	0
May	**1-2**	4	0	0	0	1	0	0	0	1	1
	2-3	5	0	0	0	0	1	0	0	0	1
	3-4	5	1	0	0	0	0	0	1	0	0
	4-1	4	1	0	0	1	0	0	1	0	0
June	**1-2**	3	0	0	1	2	0	0	0	1	0
	2-3	3	0	0	0	1	0	1	0	0	2
	3-4	5	0	0	0	0	1	0	0	0	1
	4-1	5	1	0	0	0	0	0	1	0	0
July	**1-2**	3	1	1	0	1	0	0	0	1	0
	2-3	3	0	0	0	1	1	0	1	0	1
	3-4	4	0	0	0	1	0	0	2	0	0
	4-1	4	0	0	0	0	0	1	0	2	0
August	**1-2**	3	1	0	0	0	0	0	0	0	3
	2-3	5	1	0	0	1	0	0	0	0	0
	3-4	5	0	0	0	2	0	0	0	0	0
	4-1	5	0	0	0	0	0	2	0	0	0
September	**1-2**	5	0	0	0	0	0	0	0	0	2
	2-3	6	0	0	0	1	0	0	0	0	0
	3-4	6	0	0	0	0	0	0	1	0	0
	4-1	4	2	0	0	0	0	0	0	1	0
October	**1-2**	4	0	0	0	2	0	0	0	0	1
	2-3	5	0	0	0	0	1	1	0	0	0
	3-4	4	1	0	0	0	0	0	1	0	1
	4-1	4	1	0	0	1	0	0	1	0	0
November	**1-2**	2	2	0	0	1	1	0	0	1	0
	2-3	1	0	1	0	2	1	0	1	0	1
	3-4	2	0	0	0	0	1	1	1	2	0
	4-1	3	0	0	0	0	0	0	1	1	2
December	**1-2**	2	1	0	1	0	0	0	1	1	1
	2-3	3	0	0	0	1	0	0	0	1	2
	3-4	5	0	0	0	1	0	0	0	0	1
	4-1	6	0	0	0	1	0	0	0	0	0

Table 4. Overhead Crane 10T Status Transition on January - December 2021

Months	Weeks	Status									
		P_{11}	P_{12}	P_{13}	P_{14}	P_{22}	P_{23}	P_{24}	P_{33}	P_{34}	P_{41}
January	**1-2**	4	0	0	0	1	0	0	0	2	0
	2-3	4	0	0	0	0	0	1	0	0	2
	3-4	3	2	1	0	0	0	0	0	0	1
	4-1	4	0	0	0	2	0	0	1	0	0
February	**1-2**	2	0	1	0	2	0	1	0	1	0
	2-3	2	1	0	0	0	1	0	1	0	2
	3-4	4	0	0	0	1	0	0	0	2	0
	4-1	3	0	1	0	0	1	0	0	0	2
March	**1-2**	5	0	0	0	0	0	0	2	0	0
	2-3	4	0	1	0	0	0	0	0	2	0
	3-4	4	0	0	0	0	0	0	0	1	2
	4-1	5	1	0	0	0	0	0	0	0	1
April	**1-2**	5	0	1	0	0	1	0	0	0	0
	2-3	5	0	0	0	0	0	0	2	0	0
	3-4	5	0	0	0	0	0	0	2	0	0

Table 4. Overhead Crane 10T Status Transition on January - December 2021 (Continued)

Months	Weeks	Status									
		P_{11}	P_{12}	P_{13}	P_{14}	P_{22}	P_{23}	P_{24}	P_{33}	P_{34}	P_{41}
April	**4-1**	4	1	0	0	0	0	0	1	1	0
May	**1-2**	4	0	0	0	1	0	0	0	1	1
	2-3	5	0	0	0	0	1	0	0	0	1
	3-4	5	1	0	0	0	0	0	1	0	0
	4-1	4	1	0	0	1	0	0	1	0	0
June	**1-2**	3	0	0	1	2	0	0	0	1	0
	2-3	3	0	0	0	1	0	1	0	0	2
	3-4	5	0	0	0	0	1	0	0	0	1
	4-1	5	1	0	0	0	0	0	1	0	0
July	**1-2**	3	1	1	0	1	0	0	0	1	0
	2-3	3	0	0	0	1	1	0	1	0	1
	3-4	4	0	0	0	1	0	0	2	0	0
	4-1	4	0	0	0	0	0	1	0	2	0
August	**1-2**	3	1	0	0	0	0	0	0	0	3
	2-3	5	1	0	0	1	0	0	0	0	0
	3-4	5	0	0	0	2	0	0	0	0	0
	4-1	5	0	0	0	0	0	2	0	0	0
September	**1-2**	5	0	0	0	0	0	0	0	0	2
	2-3	6	0	0	0	1	0	0	0	0	0
	3-4	6	0	0	0	0	0	0	1	0	0
	4-1	4	2	0	0	0	0	0	0	1	0
October	**1-2**	4	0	0	0	2	0	0	0	0	1
	2-3	5	0	0	0	0	1	1	0	0	0
	3-4	4	1	0	0	0	0	0	1	0	1
	4-1	4	1	0	0	1	0	0	1	0	0
November	**1-2**	2	2	0	0	1	1	0	0	1	0
	2-3	1	0	1	0	2	1	0	1	0	1
	3-4	2	0	0	0	0	1	1	1	2	0
	4-1	3	0	0	0	0	0	0	1	1	2
December	**1-2**	2	1	0	1	0	0	0	1	1	1
	2-3	3	0	0	0	1	0	0	0	1	2
	3-4	5	0	0	0	1	0	0	0	0	1
	4-1	6	0	0	0	1	0	0	0	0	0

3.1. Probability of The Machine Status Transition

From the engine status transition data, the probability of the engine status transition is calculated from the proportion of the number of each condition, namely good or 'baik' (B), lightly damaged or 'kerusakan ringan' (Kr), moderately damaged or 'kerusakan sedang' (Ks), and heavily damaged or 'kerusakan berat' (Kb). Then it is made in the form of an initial matrix which is the maintenance carried out by the company. Based on the transition probability table for the radial drilling machine, the probability value for each condition is obtained :

- Good condition (B)
  B to B : 0,8761
  B to Kr : 0,0826
  B to Ks : 0,0321
  B to Kb : 0,0092
- Lightly damaged condition (Kr)
  Kr to Kr : 0,6000
  Kr to Ks : 0,2222

Kr to Kb : 0,1778

- Heavily damaged condition (Ks)
  Ks to Ks : 0,5116
  Ks to Kb : 0,4884
- Moderately damaged condition (Kb)
  Kb to B :1

Meanwhile, based on the transition probability table for the 10T overhead crane machine, the probability value for each condition is obtained :

- Good condition (B)
  B to B : 0,8611
  B to Kr : 0,1181
  B to Ks : 0,0139
  B to Kb : 0,0069
- Lightly damaged condition (Kr)
  Kr to Kr : 0,5385
  Kr to Ks : 0,2564
  Kr to Kb : 0,2051
- Heavily damaged condition (Ks)
  Ks to Ks : 0,5172
  Ks to Kb : 0,4828
- Moderately damaged condition (Kb)
  Kb to B : 1

3.2. Probability of Steady-State Machine Status

Gleaned from the probability value for each condition, the steady-state probability for the radial drilling machine can be written as follows:

$$\begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} = [\pi_1 \ \pi_2 \ \pi_3 \ \pi_4] \begin{bmatrix} 0,8761 & 0,0826 & 0,0321 & 0,0092 \\ 0 & 0,6000 & 0,2222 & 0,1778 \\ 0 & 0 & 0,5116 & 0,4884 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

The results :

$\pi_1 = 0,6712$ $\pi_2 = 0,1385$ $\pi_3 = 0,1072$

$\pi_4 = 0,0831$

The steady-state probability for the overhead crane 10T can be written as follows:

$$\begin{bmatrix} \pi_1 \\ \pi_2 \\ \pi_3 \\ \pi_4 \end{bmatrix} = [\pi_1 \ \pi_2 \ \pi_3 \ \pi_4] \begin{bmatrix} 0,8658 & 0,1141 & 0,0134 & 0,0067 \\ 0 & 0,5385 & 0,2564 & 0,2051 \\ 0 & 0 & 0,5172 & 0,4828 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

The results :

$\pi_1 = 0,6491$ $\pi_2 = 0,1605$ $\pi_3 = 0,1033$

$\pi_4 = 0,0625$

From the initial transition probability, which is the company's machine maintenance method, then a similar calculation is carried out to find the recommended transition probability. There are 4 suggestions for machine maintenance :

1. Corrective maintenance on status 4 and preventive maintenance on status 3.
2. Corrective maintenance on status 3 and 4, preventive maintenance on status 2.
3. Corrective maintenance on status 4 and preventive maintenance on status 2 and 3.
4. Corrective maintenance on status 3 and status 4.

Then the probability is obtained in a steady-state for the long term on each machine.

Table 5. Status Probability Radial Drilling Machine

Maintenance Activities	Probability			
	(π_1)	(π_2)	(π_3)	(π_4)
P_0	0,6712	0,1385	0,1072	0,0831
P_1	0,5142	0,3318	0,0903	0,0637
P_2	0,8898	0,0735	0,0286	0,0082
P_3	0,8651	0,0992	0,0278	0,0079
P_4	0,7517	0,1552	0,0586	0,0345

Table 6. Status Probability Overhead Crane 10T

Maintenance Activities	Probability			
	(π_1)	(π_2)	(π_3)	(π_4)
P_0	0,6491	0,1605	0,1033	0,0625
P_1	0,5189	0,3221	0,0895	0,0696
P_2	0,8817	0,1006	0,0118	0,0059
P_3	0,8714	0,1111	0,0117	0,0058
P_4	0,7238	0,1789	0,0556	0,0417

P_0 is a maintenance activity belonging to the company, while P_1, P_2, P_3 dan P_4 are recommended maintenance activities.

3.3. Maintenance Cost

Maintenance costs are known from the multiplication of maintenance time (for each policy) with downtime costs so that the costs of preventive maintenance (C_{1i}) and corrective maintenance costs (C_{2i}) are obtained and are presented in table below.

Table 7. Preventive and Corrective Maintenance Cost

Machines	Preventive Maintenance Costs (Rp)	Corrective Maintenance Costs (Rp)
Radial Drilling	43.242.500	148.260.000
Overhead Crane 10T	48.750.000	119.437.500

3.4. Expected Average Maintenance Cost

Based on maintenance costs for each item. If these costs are linked to the probability that the status will remain stable in the long run, the predicted average price for each treatment can be calculated (Nurafifah, 2021).

Table 8. Expected Average Cost per Unit Time

Maintenance Activities	Expected Average Cost Per Unit Time (Rp)	
	Radial Drilling	Overhead Crane 10T
P_0	12.320.406	7.464.844
P_1	13.348.960	12.675.975
P_2	8.634.292	7.018.294
P_3	6.663.052	6.679.238
P_4	13.803.006	11.621.269

The minimum expected average cost (Table 8) for both radial drilling machines and 10T overhead cranes is obtained from the 3rd recommendation, namely by applying preventive repairs to status 2 and 3, and corrective maintenance to status 4. Total maintenance costs of P_3 recommendation amounting to Rp13.342.290,00 is much cheaper when compared to the total maintenance cost of the company P_0 amounting to Rp19.785.250,00. So that cost savings are received if the maintenance recommendations are implemented.

3.5. Cost Savings

Based on the calculation of the expected average cost per unit time, a comparison is obtained between the company's maintenance costs and the recommendation maintenance costs (obtained from the Markov Chain method) so that the percentage of savings is obtained as follows:

$$= \frac{\text{Rp}19.785.250{,}00 - \text{Rp}13.342.290{,}00}{\text{Rp}19.785.250{,}00} \times 100\%$$

$$= 33\%$$

3.6. Maintenance Scheduling Planning Using the Markov Chain Method

By applying the recommended maintenance using the Markov Chain method, the machine maintenance time (suggested) for one year can be known through the following calculation :

$$\frac{\text{recommended maintenance cost}}{\text{company maintenance costs}} \times \Sigma \text{ corrective maintenance time}$$

$$= \frac{\text{Rp}13.342.290{,}00}{\text{Rp}19.785.250{,}00} \times 193{,}5 \text{ hours}$$

$$= 130{,}487 \text{ hours} \approx 130{,}5 \text{ hours}$$

Recommended maintenance takes 130,5 hours and requires an average cost of maintenance expectations of Rp13.342.290,00, where the determination of the machine maintenance interval is obtained from the following formula:

$$\frac{\text{CM for each machine}}{\Sigma \text{ CM time}} \times \Sigma \text{ recommended maintenance time}$$

Recommended maintenance interval for the radial drilling machine.

$$= \frac{120 \text{ hours}}{193{,}5 \text{ hours}} \times 130{,}5 \text{ hours}$$

$$= 80{,}9 \text{ hours}$$

So the maintenance is carried out every:

$$= \frac{80{,}9 \text{ hours}}{193{,}5 \text{ hours}} \times 12 \text{ months}$$

$$= 5{,}018 \text{ months} \approx 5 \text{ months}$$

Recommended maintenance interval for the overhead crane 10T

$$= \frac{73{,}5 \text{ hours}}{193{,}5 \text{ hours}} \times 130{,}5 \text{ jam}$$

$$= 49{,}66 \text{ hours}$$

So the maintenance is carried out every :

$$= \frac{49{,}66 \text{ hours}}{193{,}5 \text{ hours}} \times 12 \text{ months}$$

$$= 3{,}074 \text{ months} \approx 3 \text{ months}$$

3.7. Discussion

Based on the processing results from the existing data, it can be seen that the maintenance costs of the company's method and the maintenance costs of the Markov Chain method are presented in the form of a Table 9.

Table 9. Maintenance Cost of Company Method and Markov Chain Method

Machines	Company's Method Maintenance Cost	Markov Chain Method Maintenance Cost	Maintenance interval planning
RD	Rp12.320.406,00	Rp6.663.052,00	Must hold every 5 months
OHC 10T	Rp 7.464.844,00	Rp6.679.238,00	Must hold every 3 months

4. CONCLUSION AND SUGGESTION

Following the completion of the investigation and data processing, the following findings can be drawn:

1. From the company's maintenance conditions, the costs incurred to carry out maintenance based on downtime costs in January - December 2021 amounted to Rp19,785,250.00 consisting of radial drilling machine maintenance costs Rp12,320,406.00 and overhead crane maintenance costs of 10T amounting to Rp7,464,844.00.
2. From the cheapest proposed maintenance (P_3) using the Markov Chain method, the total proposed maintenance cost is Rp.

13,342,290.00 consisting of radial drilling machine maintenance of Rp. 6,663,052.00 with maintenance planning every 5 months and overhead crane maintenance costs 10T amounting to Rp6,679,238.00 with maintenance planning every 3 months.
3. The results of the calculation and discussion of the data prove that the Markov Chain method can be used as a reference to determine maintenance intervals for radial drilling machines and 10T overhead cranes in the future because the results obtained are proven to be more effective and can reduce machine maintenance costs based on downtime costs at PT. BBI

Some recommendations for the company are made based on the conclusion.

1. The company's machine maintenance system should be performed regularly and on a scheduled basis to reduce engine damage, for example, by implementing maintenance proposal 1 for radial drilling machines and 10t overhead cranes.
2. Recording maintenance data should be carried out in detail and regularly to prepare maintenance models for other research. in the future.

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