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STRATEGIES OF MAINTENANCE MODEL FOR EXERCISE BOOK MANUFACTURING MACHINE ON PAPER INDUSTRY BY IMPLEMENTING MONTE CARLO SIMULATION APPROACH

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Abstract *PT. XYZ is one of paper companies in East Java that produces Exercise Books. This company used corrective maintenance for Exercise Book machine. This corrective maintenance brings about high frequency of the machine breakdown and high maintenance cost. Therefore, to solve the problem required the interval maintenance planning. There are 3 maintenance scenarios, namely; scenario based on the existing condition of the company, scenario of component replacement in accordance with Mean Time to Failure (MTTF) value, and scenario of component replacement when the reliability of the component has reached 70%. From those three scenarios we will manually carry out an interval maintenance planning and Monte Carlo simulation. The result of data processing shows that in order to minimize the number of Exercise Book machine breakdown we can apply the 3rd scenario namely the replacement of component when the reliability of component has reached 70%. Proper maintenance strategy to minimize the amount of downtime and maintenance costs appropriately we shall use scenario 2, namely the replacement of component based on the Mean Time To Failure (MTTF).*

Key words: *Exercise Book Machine, Mean Time to Failure, Component Reliability, Monte Carlo Simulation.*

1. Preface

Today's advance of technology and development of the industry require companies to move quickly in making innovations and specific policies in order to compete in the industrial world. One of the policies that can be applied in the company is the policy on maintenance. Maintenance is all activities conducted to maintain or restore the condition of the equipment or machinery in accordance with the desired function [1].

PT. XYZ is a paper manufacturing company in East Java, which produces Exercise Books. In order to meet high demand for its Exercise Book product, the company operates for 24 hours with three shifts. By implementing 24 hours' operating system, the company applies a corrective system to maintain its machine, namely the replacement of component when the machine is damaged. This maintenance system causes frequent sudden machine stopping during production process. It may trigger further damage to raw materials during machinery processing, causing losses for the company.

To minimize this, better interval maintenance planning is required in order to reduce the frequency of breakdowns that occur suddenly. Another goal is to minimize downtime and costs due to maintenance activities. In practice it is extremely difficult to determine the operational or maintenance strategy facilities strategies in order to reduce maintenance costs [2]. The uncertainty in preventive maintenance activities can be solved by using model parameters which are made to achieve the expected target. Monte Carlo simulation can predict future performance [3]. The method used for the analysis of maintenance costs must be able to measure the effect of the operating environment on the reliability of the system and measure of uncertainty [4]. Monte Carlo method is often referred to as statistical simulation method. This method can be used in many areas or places to solve the problem containing uncertainty [5].

The above-mentioned preliminary researches can be used as consideration in solving the problem at PT. XYZ Company. In order to plan maintenance interval that contains uncertainty we can perform an analysis by implementing Monte Carlo simulation.

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2. Research Methodology

The method used is to determine the scenario of machinery maintenance with Monte Carlo simulation machine. There are 3 maintenance scenario that are used, namely the scenario based on the existing condition of the company, the scenario of component replacement based on Mean Time to Failure (MTTF) value, and the scenario of component replacement when the reliability of component has reached 70%. From those 3 scenarios the planning of maintenance interval is carried out manually and Monte Carlo simulation is implemented.

The key of the Monte Carlo method is the use of random number which will be raised and during the simulation process. The random number is generated based on the probability distribution of the data processed. Random number used in the Monte Carlo simulation that has been raised must be validated with available real data so that the simulation that we do has similar condition with real data.

3. Result and Discussion

The data on the frequency of the damage of Exercise Book Machine Units (EBMU) can be seen in Table.1 below.

Table 1. Frequency of the Damage of EBMU

COMPONENT	2013	2014	2015	Frequency of The Damage (times)
PRINTING	50	80	57	187
TRIMMING	39	51	51	141
LONG KNIFE	35	31	48	114
STITCHING	23	27	42	92
CROSS CUTTING	30	38	12	80
BACK PRESING	10	10	34	54
UNWIND	3	6	22	31
COLECTING	8	11	4	23
DELIVERY	3	5	4	12
BACK STAND	4	1	6	11
FOLDING	0	4	3	7
TOTAL	**205**	**264**	**283**	**752**

Based on the Table 1 we can observe that the critical machinery unit is reached by printing machine with the total damage as much as 187 times. So this research is focused on the printing unit. With the number of components in the printing unit is amounted to 8 components.

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3.1. Estimation of Distribution

Value of selected Fit Index (r) is the index of Fit (r) which has the greatest value where at the same time plays the role as the estimation of the type of distribution for each component.

Table 2. Recapitulation of the Estimation of Data Distribution of TTF Component for Printing Machine Unit

Component	Index of fit (r) Weibull Distribution	Index of fit (r) Lognormal Distribution	Index of fit (r) Normal Distribution	Estimation of Distribution (TTF)
Klise	0.969	0.994	0.916	Lognormal
Weber	0.929	0.979	0.811	Lognormal
Gear Inking	0.989	0.973	0.930	Weibull
Bearing Impresing	0.982	0.938	0.989	Normal
Anilog	0.983	0.968	0.915	Weibull
Gear Impresing	0.983	0.986	0.961	Lognormal
Bearing Inking	0.975	0.953	0.974	Weibull
Bearing Maindril	0.901	0.949	0.847	Lognormal

3.2. Fit of Distribution Test

From the highest value of Index of Fit (r), the estimation of initial distribution of each component is selected. The next step is performing distribution test to each component. Distribution test for Lognormal and Nornal distribution was conducted by using Kolomogorov Smirnov test. For Weibull distribution, the fit of distribution test is implemented by using Mann T Test.

3.3. Determination of the Parameters and the Value of Mean Time to Failure (MTTF) of the Component of Printing Machine Unit

After we know that the fit of distribution test to the data has been in accordance with the initial estimation of distribution, we need to determine the parameters for Time to Failure (TTF) data for each component. The value of Time to Failure (TTF) data parameter will be used to determine the Mean Time to Failure (MTTF) value.

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Table 3. Parameter and MTTF Value of TTF Data of the Component of Printing Machine Unit

Component	Distribution (TTF)	Parameter	MTTF (minute)
Klise	Lognormal	Loc (μ)= 9.64519	21091.42
		Scale (σ) = 0.789217	
Weber	Lognormal	Loc (μ)= 10.0235	36520.16
		Scale (σ) = 0.981957	
Gear Inking	Weibull	Scale (θ)= 97454	96254.34
		Shape (β)= 1.03016	
Bearing Impresing	Normal	Mean (μ)= 96625	96625
		St.dev(σ)= 53252.5	
Anilog	Weibull	Scale (θ)= 93899.4	99732.43
		Shape (β)= 0.881997	
Gear Impresing	Lognormal	Loc (μ)=11.367	117539.3
		Scale (σ) = 0.784255	
Bearing Inking	Weibull	Scale (θ)= 115403	105314.5
		Shape (β) =1.3763	
Bearing Maindril	Lognormal	Loc (μ)=11.2327	127620.2
		Scale (σ) = 1.02383	

3.4. Determination of Parameter and Value of Mean Time to Repair (MTTR) of the Component of Printing Machine Unit

The next stage after identifying that the distribution of fit test data has been in accordance with the initial estimate of the distribution is to determine the parameters for data Time to Repair (TTR) for each component. The value of this data parameter of Time to Repair (TTR) will be used to determine the value of Mean Time to Repair (MTTR).

Table 4. Parameter and MTTR of TTR Data of the Component of Printing Machine Unit

Component	Distribution (TTR)	Parameter	MTTR (minute)
Klise	*Lognormal*	*Loc (μ)= 4.47729*	*117.81539*
		Scale (σ) = 0.763975	
Weber	*Lognormal*	*Loc (μ)= 3.50666*	*38.86431*
		Scale (σ) = 0.553925	
Gear Inking	*Normal*	*Mean (μ)= 76*	*76*
		St.dev(σ)= 34.7818	
Bearing Impresing	*Lognormal*	*Loc (μ)= 4.18151*	*87.47994*
		Scale (σ) = 0.761446	
Anilog	*Lognormal*	*Loc (μ)= 4.39431*	*92.95275*
		Scale (σ) = 0.524939	
Gear Impresing	*Lognormal*	*Loc (μ)= 3.95813*	*70.01784*
		Scale (σ) = 0.762391	
Bearing Inking	*Weibull*	*Scale (θ)=121.697*	*107.8284*
		Shape (β)=2.28962	
Bearing Maindril	*Normal*	*Mean (μ)= 90*	*90*
		St.dev(σ)= 24.5241	

3.5. Generation of Maintenance Scenario

The maintenance scenario will be simulated to determine the type of maintenance and proper interval of replacement for each critical component. There are 3 proposed maintenance scenarios, namely: In scenario 1, critical component is replaced based on the existing condition of the company. Scenario 2, component is replaced in accordance with MTTF values, and for scenario 3: component will be replaced when the reliability of the component has reached 70%.

Table 5. Recapitulation of the Scenario of Maintenance Interval of the Component of Printing Machine Unit

Component	Scenario 1	Scenario 2 (MTTF)	Scenario 3 Reliability70%
Klise	Actual Data	21091.42	10167
Weber	Actual Data	36520.16	13400
Gear Inking	Actual Data	96254.34	33740
Bearing Impresing	Actual Data	96625	68401
Anilog	Actual Data	99732.43	37900
Gear Impresing	Actual Data	117539.3	57030
Bearing Inking	Actual Data	105314.5	29900
Bearing Maindril	Actual Data	127620.2	43900

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Actual Data Time to Failure (TTF) and Time to Repair (TTR) for Bearing Maindrill listed in the Table 6.

Table 6. The actual Data TTR and TTF Bearing Maindrill

Date	Start (time)	Finish (time)	TTR (minute)	TTF (minute)
May 16, 2014	18:22	20:02	100	0
June 6, 2014	21:15	23:00	105	30313
July 11, 2014	19:03	20;03	60	50163
August 6, 2014	08:14	09:39	85	36731
Sept 17, 2014	16:34	17:34	60	60895
May 29, 2015	07:51	09:31	100	365177
Sept 10, 2015	11:12	13:12	120	149861

3.6. Random Number Generation

The generation of random number for Time to Failure (TTF) data and Time to Repair (TTR) of the component of Exercise Book machine unit is the stage to run a Monte Carlo simulation. Random number that will be raised is based on the probability distribution of the initial data Time to Failure (TTF) and Time to Repair (TTR) that exist in the company. The generation of random numbers Time to Failure (TTF) and Time to Repair (TTR) components of the machine unit Exercise Book is intended to produce figures that have equal distribution with data population of Time to Failure (TTF) and Time to Repair (TTR) of the actual component of Exercise Book machine unit. The first step in generating random number is to determine the probability distribution of the data variables of Time to Repair (TTR) for each component of the machine unit.

Table 7. Distribution of Probability Data of TTR Bearing Maindrill Based on Actual Condition

TTR (minute)	Frekuensi (times)	Probability Distribution
60	2	2/7 = 0.286
85	1	1/7 = 0.143
100	2	2/7 = 0.286
105	1	1/7 = 0.143
120	1	1/7 = 0.143
Total	**7**	**1**

Based on Table 7 so set the cumulative probability distribution of TTR Data of the component Bearing Maindrill.

Table 8. Cumulative Probability Distribution of TTR Data of the Component of Bearing Maindrill

TTR (minute)	Probability Distribution	Cumulative Probability Distribution
60	2/7 = 0.286	0.286
85	1/7= 0.143	0.429
100	2/7 = 0.286	0.714
105	1/7 = 0.143	0.857
120	1/7 = 0.143	1.000

Determine the random number for Time to Repair (TTR) data of which interval of random number has been predetermined on the previous stage.

1	0.953	0.438	0.655
2	0.239	0.572	0.487
3	0.815	0.546	0.257
4	0.661	0.508	0.166
5	0.303	0.636	0.090
6	0.588	0.116	0.295
7	0.109	0.527	0.780
8	0.777	0.308	0.763
9	0.084	0.720	0.480
10	0.732	0.646	0.933
11	0.457	0.416	0.906
12	....	.....	......
92	0.051	0.656	0.935
93	0.046	0.623	0.703
94	0.268	0.568	0.968
95	0.703	0.003	0.838
96	0.959	0.285	0.818
97	0.293	0.204	0.185
98	0.025	0.251	0.481
99	0.125	0.294	0.221
100	0.625	0.060	0.106

Figure 1. Random Number Generation of TTR Data of the Component of Bearing Maindrill.

The next phase is to develop a random number of Time to Repair (TTR) data based on the random number that was generated in Excel

Table 9. *Time to Repair Bearing Maindrill Value* Result of Random Number Generation

Random Number Replication 1	Value TTR Generation Replication 1	Random Number Replication 2	Value TTR Generation Replication 2	Random Number Replication 3	Value TTR Generation Replication 3
0.953	120	0.438	100	0.655	100
0.239	60	0.572	100	0.487	100
0.815	105	0.546	100	0.257	60
0.661	100	0.508	105	0.166	60
0.303	85	0.636	100	0.090	60
0.588	100	0.116	60	0.295	85
0.109	60	0.527	100	0.780	105
0.777	105	0.308	85	0.763	105
0.084	60	0.720	105	0.480	100

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Random Number Replication 1	Value TTR Generation Replication 1	Random Number Replication 2	Value TTR Generation Replication 2	Random Number Replication 3	Value TTR Generation Replication 3
0.732	105	0.646	100	0.933	120
0.457	100	0.416	85	0.906	120
0.007	60	0.802	105	0.128	60
0.376	85	0.371	85	0.003	60
0.091	60	0.608	100	0.134	60
0.137	60	0.831	105	0.909	120
0.337	85	0.729	105	0.634	100
0.089	60	0.692	100	0.859	120
0.672	100	0.770	105	0.052	60

3.7. Simulation Based on each Scenario

This simulation process is done based on three scenarios that have been established for each component. This simulation is planned for 1 year (365 days) with 3 replication for each scenario.

In addition to the calculation of maintenance interval with simulation, the calculation of interval maintenance is also made without the simulation process. It aims to determine to find out the maintenance interval in ideal conditions and the maintenance interval based on the possibility in the future with Monte Carlo simulation.

3.8. The Analysis of the Maintenance Interval of EBMU Based on Monte Carlo Simulation

The maintenance simulation performed to EBMU is based on the interval scenario of the replacement that was previously determined. It aims to identify the amount of the damage and downtime as the consideration to determine appropriate models of maintenance.

Table 10. The Recapitulation of Total Maintenance and Downtime Based on Simulation

Maintenance Scenario	TM(times)		TD (minute)		TM Total (times)	TD Total (minute)
	CM	PM	CM	PM		
Scenario 1	62	-	6310	-	62	6310
Scenario 2	22	50	1485	3222	72	4707
Scenario 3	13	152	857	11655	165	12512

TM : Total Maintenance
TD : Total Downtime
CM : Corrective Maintenance
PM : Preventive Maintenance

The recapitulation of maintenance and breakdown on the result of simulation for Printing machine unit can be perceived that scenario 2, namely the replacement of component based on the MTTF value has the lowest downtime value of 4707 minutes. Despite having more total maintenance than scenario 1, the total downtime of scenario 2 remains the smallest.

3.9 Analysis of Maintenance Cost for EBMU Based on the Calculation without Simulation

After calculating the costs incurred by the company in the context of the maintenance of the component of the EBMU for each scenario, we can observe the cost difference between those three maintenance scenarios conducted without simulation process. The following is the recapitulation of the result of calculation of the maintenance cost for the EBMU based on each maintenance scenario.

3.10. Analysis of Maintenance Interval of the EBMU without Simulation

The planning of maintenance interval of the component EBMU based on each maintenance scenario aims to identify the total number of maintenance and the total maintenance downtime in ideal conditions

Table 11. The Recapitulation of the Total Maintenance and the Total Downtime of the EBMU without Simulation

Maintenance Scenario	TM(times)		TD(minute)		TM Total (times)	TD Total (minute)
	CM	PM	CM	PM		
Scenario 1	70	-	5485	-	70	5485
Scenario 2	-	67	-	5054.51	67	5054.51
Scenario 3	-	162	-	8206.97	162	8206.97

TM : Total Maintenance
TD : Total Downtime
CM : Corrective Maintenance
PM : Preventive Maintenance

Based on the maintenance interval without the simulation process for the Exercise

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Book machine unit, it can be seen that scenario 2, namely; the replacement of component based on the MTTF value has the lowest downtime value of 5054.51 minutes compared with the value of downtime of the other scenarios. This is because the researchers group various intervals that have the same type of maintenance into one group so that the machine does not stop frequently. For the amount of maintenance in scenario 2 of 67 times is less than scenario 1 maintenance with the amount of maintenance as many as 70 times and scenario 3 that is as many as 162 times.

3.11. Analysis of Maintenance Cost for EBMU Based on the Calculation without Simulation

After calculating the costs incurred by the company in the context of the maintenance of the component of the EBMU for each scenario, we can observe the cost difference between those three maintenance scenarios conducted without simulation process. The following is the recapitulation of the result of calculation of the maintenance cost for the EBMU based on each maintenance scenario.

From the above-mentioned data it can be seen the maintenance scenario that produce the lowest maintenance cost to the EBMU is scenario 2 (the replacement of component based on the value of MTTF) in the amount of $ 13346.51. Scenario 2 has smaller maintenance cost compared to other scenarios because it has smaller downtime value than other scenarios.

Table 12. The Recapitulation of the Result of Cost Calculation for EBMU without Simulation Process

Scenario	Corective Cost ($)	Preventive Cost ($)	Total Cost ($)
Scenario 1	13577	-	13577
Scenario 2	-	13346.51	13346.51
Scenario 3	-	29181.97	29181.97

Analysis of Maintenance Cost for the EBMU Based on Simulation. The following is the recapitulation of cost calculation for the EBMU based on three scenarios with simulation process.

Table 13. The Recapitulation of the Cost Calculation for the EBMU Based on Simulation

Scenario	Corective Cost ($)	Preventive Cost ($)	Total Cost ($)
Scenario 1	13264	-	13264
Scenario 2	4537	8630.67	13167.67
Scenario 3	2594.67	31069	33663.67

From the calculation we can observe that the maintenance scenarios which produces the lowest maintenance cost to the EBMU is scenario 2 (the replacement of component based on the value of MTTF) in the amount of $ 13167.67. Scenario 2 has smaller maintenance cost compared other scenarios because it has smaller downtime value than other scenarios.

4. Conclusion

Based on the result and discussion that have been conducted by the researchers, the conclusions which can be drawn are among others:

1. Critical machine unit on the Exercise Book machine is a machinery unit that has high frequency of damage. Critical machine unit on the Exercise Book machine is Printing machine unit with the total damage of 187 times, 2. For the average time interval for component reparation of the Exercise Book machine unit which includes cliché component with the time interval of reparation of 117.81539 minutes, Weber component of 38.86431 minutes, inking Gear component of 76 minutes, Bearing Impressing component of 87.47994 minutes, Anilog component of 92. 95275 minutes, Gear Impressing component of 70.01784 minutes, Bearing Maindrill component of 90 minutes,
2. The most appropriate maintenance strategy with Monte Carlo simulation aimed to minimize the frequency of the breakdown of Exercise Book (EB) machine unit is the maintenance scenario 3 which is the replacement of the component when the value of the reliability of the component has reached 70%, with a total number of breakdown frequency of the Exercise Book machine unit reaching 13 times.
3. The most appropriate maintenance strategy with Monte Carlo simulation aimed to

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minimize the cost of maintenance is the scenario 2 which is the replacement of the component of the Exercise Book machine unit based on the value of MTTF with the maintenance cost amounting to $ 13,167.67. Whereas the most appropriate scenario aimed to minimize machine downtime of the Exercise Book machine unit is scenario 2, namely the replacement of the component of the Exercise Book machine unit based on the value of MTTF, with the value of downtime of 4707 minutes or decreases 25.40% compared to scenario 1 which is the replacement of the component based on the existing condition of the company where the new component will be replaced if the said component experiencing damaged.

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