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Alternative Centrifugal Pump Maintenance Systems Using Reliability Centered Maintenance (RCM II) and Life Cycle Cost (LCC) Methods in PDAM Surya Sembada Surabaya

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Abstract: *The purpose of this study was to determine the pump failure factors, determine alternative pump maintenance intervals as an alternative maintenance policy, and minimize maintenance costs using the cost calculation method (LCC). In this study, observations and interviews were carried out to obtain data related to the centrifugal pump machine. From the LCC (Life Cycle Cost) calculation above, it can be seen based on table 4.20, it is found that the smallest cost value is in year (n) = 5 with the number of mechanics (M) = 3 with the result of calculating a total cost of Rp. 1,515,507,735. So, it can be concluded that TC2 < TC1 with these results, the proposed method in this study is accepted. The maintenance interval for each centrifugal pump component is for the Impeller of 1,673 hours by selecting the Discard task, Shaft of 698 hours by selecting the scheduled restoration task, Bearing by 322 hours by selecting the scheduled restoration task, Coupling by 698 hours by selecting the scheduled restoration task, Mechanical seal for 2,131 hours with the selection of the scheduled discard task. The results of the calculation of the total cost of Rp. 1,515,507,735 as TC2 with a total company cost of IDR 1,600,000,000. So, it can be concluded that TC2 < TC1.*
Keywords: *pump maintenance; PDAM; systems*

I. Introduction

Technological developments each year experience a significant increase from the previous year, causing human needs to increase. The increase in human needs causes every company to improve their production processes to meet these needs.

PDAM Surya Sembada Surabaya is a regional company that produces clean water for the Surabaya area. Clean water is obtained through a process in the installation unit by taking raw water from the Jagir River. PDAM Surya Sembada Surabaya has 2 installation sites, namely IPAM Ngagel and IPAM Karangpilang. IPAM Ngagel is divided into 3 production sites, namely Ngagel 1, Ngagel 2, and Ngagel 3. Each production site produces ± 1500 liters/second of clean water. The production process starts from pre-sedimentation to the pump house.

Data breakdown survey above it can be seen that the total breakdown of the pump engine at Ngagel 1 is 93.85 hours. From these data it can be seen that the Ngagel 1 pump engine, which is 25 years old, has a total breakdown with 45 incidents during 2021. The breakdown of the pump engine is in several components, namely the impeller, shaft, bearing, coupling, and mechanical seal. The breakdown of some of these components can disrupt the ongoing production process so that repair and maintenance actions are needed.

The maintenance applied at PDAM Surya Sembada Surabaya is preventive care. PDAM implements preventive maintenance in order to maintain the quality and quantity of clean water it produces. Preventive maintenance is treatment that has the goal of preventing damage. Preventive maintenance has scopes such as inspections, minor repairs, lubrication and adjustments. In preventive maintenance, maintenance planning is carried out for each engine component at different times, there are several machines that have a maintenance period of 1 week a month to 3 months. In weekly inspections there are often several components that need to be acted on prior to maintenance time.

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In the problem at PDAM Surya Sembada Surabaya, the researcher suggests an alternative treatment system using the methodReliability Centered Maintenance (RCM) to determine maintenance intervals to reduce maintenance costs. According to Didik (2021), Reliability Centered Maintenance (RCM) is a method for determining maintenance tasks that will guarantee a reliability system design. RCM serves to address the dominant causes of failure which will lead to maintenance decisions that focus on preventing the occurrence of frequent types of failures.

II. Review of Literature

2.1 Maintenance

According to Sofyan Assauri (1999) maintenance is an activity to maintain or maintain factory facilities or equipment and make necessary repairs or adjustments or replacements so that there is a state of satisfactory production operations in accordance with what was planned. In general, a product that is produced by humans, nothing is impossible to be damaged, but the age of its use can be extended by carrying out repairs known as maintenance. Therefore, in a company, maintenance activities are needed which include maintenance and maintenance of machines used in the production process (Corder, 1992).

2.2 RCM (Reliability Centered Maintenance)

Reliability Centered Maintenance (RCM) is a method for determining maintenance tasks that will ensure a reliable system design. RCM serves to address the dominant causes of failure which will lead to maintenance decisions that focus on preventing the occurrence of frequent types of failures. The RCM approach to the maintenance program views that a facility does not have financial and resource limitations, so it needs to be prioritized and optimized. In summary, RCM is a systematic approach to evaluate a facility and its resources for high reliability and cost effectiveness. RCM is very dependent on predictive maintenance but also realizes that maintenance activities on equipment that are not expensive and not important to equipment reliability are better done with a reactive maintenance approach. The RCM approach in carrying out the dominant maintenance program is predictive with the following division:

1. <10% reactive
2. 25%-35% preventive
3. 45%-55% predictive

2.3 Reliability

According to Ebelling (1997) reliability is the probability that a component or system will operate according to the specified function within a certain period of time when used under certain operational conditions. Reliability also means the ability of an equipment to survive and continue to operate until a certain time limit. The measure of the success of a maintenance action (miantenance) can be expressed by the level of reliability. In general, reliability can be defined as the probability that a system or product can operate properly without being damaged under certain conditions and at a predetermined time. Based on the definition of reliability is divided into four main components, namely:

2.4 Damage Distribution Function

This distribution function is very important because it is closely related to probability. In the application of preventive maintenance, the damage time data to be calculated is the measurement result, so this data is included in continuous data. Therefore, the distribution used to calculate the breakdown time and repair time is the normal (Gaussian), Lognormal, Exponential, and Weibull distribution.

2.5 Determination of Time to Failure (TTF) and Time to Repair (TTR) Distribution

The process of determining the distribution for TTF and TTR data for each critical component is to make a hypothesis whether the damage data follows the Weibull distribution where the distribution is related to the damage rate. After estimating the types of distribution of TTF and TTR data, the next step is to carry out a goodness of fit test on the TTF and TTR data obtained to ensure whether the suspected data distribution pattern conforms to a certain distribution pattern to be further processed to obtain the parameters of each. components according to the selected distribution.

III. Research Methods

The information needed in this research is centrifugal pump, reliability centered maintenance, failure mode and effects analysis, and life cycle cost. Field studies are carried out by observing field conditions directly. In this study, observations and interviews were carried out to obtain data related to the centrifugal pump machine.

IV. Discussion

4.1 Results

Data collection

a. Machine Data and Components

Machine data and components can be seen in table 1 as follows:

Table 1. Machine Data and Components

No	Machine	Component
1	Centrifugal Pump	*Impeller*
2		*Shafts*
3		*Bearings*
4		*Clutch*
5		*Mechanical seals*

Source: Secondary data

b. Downtime Data

Downtime data from January 2021 to December 2021 can be seen in table 2 as follows:

Table 2. Centrifugal Pump Engine Downtime Data

No	Damage Date	Machine name	Component Name	*Downtime* (minute)
1	4/1/2021	Centrifugal pump	*Bearings*	158
2	18/1/2021	Centrifugal pump	*Bearings*	149
3	27/1/2021	Centrifugal pump	*Shafts*	140
4	8/2/2021	Centrifugal pump	*Bearings*	148
5	18/2/2021	Centrifugal pump	*Clutch*	80

6	22/2/2021	Centrifugal pump	*Bearings*	149
7	22/2/2021	Centrifugal pump	*Shafts*	130
8	3/3/2021	Centrifugal pump	*Impeller*	45
9	8/3/2021	Centrifugal pump	*Bearings*	154
10	22/3/2021	Centrifugal pump	*Bearings*	151
11	29/3/2021	Centrifugal pump	*Shafts*	125
12	4/4/2021	Centrifugal pump	*Mechanical Seals*	96
13	5/4/2021	Centrifugal pump	*Bearings*	147
14	19/4/2021	Centrifugal pump	*Bearings*	158
15	30/4/2021	Centrifugal pump	*Shafts*	138
16	3/5/2021	Centrifugal pump	*Clutch*	82
17	3/5/2021	Centrifugal pump	*Bearings*	151
18	17/5/2021	Centrifugal pump	*Bearings*	160
19	1/6/2021	Centrifugal pump	*Shafts*	145
0	6/6/2021	Centrifugal pump	*Impeller*	35
21	7/6/2021	Centrifugal pump	*Bearings*	148
22	16/6/2021	Centrifugal pump	*Mechanical Seals*	97
23	21/6/2021	Centrifugal pump	*Bearings*	145
24	5/7/2021	Centrifugal pump	*Bearings*	144
25	17/7/2021	Centrifugal pump	*Clutch*	73
26	19/7/2021	Centrifugal pump	*Bearings*	148
27	22/7/2021	Centrifugal pump	*Impeller*	40
28	30/7/2021	Centrifugal pump	*Shafts*	126
29	2/8/2021	Centrifugal pump	*Bearings*	145
30	16/8/2021	Centrifugal pump	*Bearings*	143
31	5/9/2021	Centrifugal pump	*Shafts*	132
32	6/9/2021	Centrifugal pump	*Bearings*	145
33	17/9/2021	Centrifugal pump	*Mechanical Seals*	86
34	20/9/2021	Centrifugal pump	*Bearings*	160
35	4/10/2021	Centrifugal pump	*Bearings*	154
36	10/10/2021	Centrifugal pump	*Shafts*	150
37	18/10/2021	Centrifugal pump	*Bearings*	141
38	18/10/2021	Centrifugal pump	*Impeller*	39
39	8/11/2021	Centrifugal pump	*Bearings*	158
40	13/11/2021	Centrifugal pump	*Clutch*	89
41	21/11/2021	Centrifugal pump	*Shafts*	120
42	22/11/2021	Centrifugal pump	*Bearings*	151
43	6/12/2021	Centrifugal pump	*Bearings*	156
44	20/12/2021	Centrifugal pump	*Bearings*	158
45	20/12/2021	Centrifugal pump	*Impeller*	42
Total				5631

Source: Secondary data

Based on the data in the table above, calculations can be made to determine the time interval between damages and the repair time for each critical component in a centrifugal pump machine. The following is the calculation of each critical component:

Example of calculating the time between component breakdowns *Impeller* starting from the date of damage to the first Impeller component to the date of the next breakdown, namely on 3/3/2021 to 6/6/2021 with a total of 38 days = 2280 hours.

Table 3. Time Data between Impeller Damage and Repair

No	Damage date	Machine	Component	*Downtime* (minute)	Time between breakdowns (Hours)
1	3/3/2021	Pump	Impeller	45	
2	6/6/2021	Pump	Impeller	35	2280
3	22/7/2021	Pump	Impeller	40	1104
4	18/10/2021	Pump	Impeller	39	2112
5	20/12/2021	Pump	Impeller	42	1536
Total				201	7032

Table 4. Time Data between Shaft Damage and Repair

No	Damage date	Machine	Component	*Downtime* (minute)	Time between breakdowns (Hours)
1	27/1/2021	Pump	Shafts	140	624
2	22/2/2021	Pump	Shafts	130	
3	29/3/2021	Pump	Shafts	125	840
4	30/4/2021	Pump	Shafts	138	792
5	1/6/2021	Pump	Shafts	145	768
6	30/7/2021	Pump	Shafts	126	1416
7	5/9/2021	Pump	Shafts	132	888
8	10/10/2021	Pump	Shafts	150	840
9	21/11/2021	Pump	Shafts	120	1008
Total				1206	7176

Table 5. Time Data between Bearing Damage and Repair

No	Damage date	Machine	Component	*Downtime* (minute)	Time between breakdowns (Hours)
1	4/1/2021	Pump	Bearings	158	
2	18/1/2021	Pump	Bearings	149	336
3	8/2/2021	Pump	Bearings	148	504
4	22/2/2021	Pump	Bearings	149	336
5	8/3/2021	Pump	Bearings	154	336
6	22/3/2021	Pump	Bearings	151	336
7	5/4/2021	Pump	Bearings	147	336
8	19/4/2021	Pump	Bearings	158	336
9	3/5/2021	Pump	Bearings	151	336
10	17/5/2021	Pump	Bearings	160	336
11	7/6/2021	Pump	Bearings	148	504

12	21/6/2021	Pump	Bearings	145	336
13	5/7/2021	Pump	Bearings	144	336
14	19/7/2021	Pump	Bearings	148	336
15	2/8/2021	Pump	Bearings	145	336
16	16/8/2021	Pump	Bearings	143	336
17	6/9/2021	Pump	Bearings	145	504
18	20/9/2021	Pump	Bearings	160	336
19	4/10/2021	Pump	Bearings	154	336
20	18/10/2021	Pump	Bearings	141	336
21	8/11/2021	Pump	Bearings	158	504
22	22/11/2021	Pump	Bearings	151	336
23	6/12/2021	Pump	Bearings	156	336
24	20/12/2021	Pump	Bearings	158	336
Total				3621	8400

Table 6. Time Data between Damage and Clutch Repair

No	Damage date	Machine	Component	*Downtime* (minute)	Time between breakdowns (Hours)
1	18/2/2021	Pump	Clutch	80	
2	3/5/2021	Pump	Clutch	82	1776
3	17/7/2021	Pump	Clutch	73	1800
4	13/11/2021	Pump	Clutch	89	2856
Total				324	6432

Table 7. Time Data between Mechanical Seal Damage and Repair

No	Damage date	Machine	Component	*Downtime* (minute)	Time between breakdowns (Hours)
1	4/4/2021	Pump	Mechanical Seals	96	
2	16/6/2021	Pump	Mechanical Seals	97	1752
3	17/9/2021	Pump	Mechanical Seals	86	2232
Total				279	3984

Based on table 3-7 it can be seen the data*downtime*for each component of the pump engine, namely as follows:

Table 8. Pump Engine Downtime Data

No	Component	Frequency	Total Downtime (minute)
1	*Impeller*	5	201
2	*Shafts*	9	1206
3	*Bearings*	24	3621
4	*Clutch*	4	324
5	*Mechanical Seals*	3	279
Total		45	5631

c. Failure Cause Data

Based on the results of interviews regarding pump engine damage with maintenance technicians, it can be concluded in table 9 below:

Table 9. Data Causes of Failure

No	Component	Function	Damage	Reason	Damage effect
1	*Impeller*	To convert the kinetic energy of the pump into velocity energy	The condition of the pump impeller is damaged and worn.	• Dirty working fluid • *Impeller*too hot • Too little lubricant • Too much lubricant.	The pump is not capable of treating water.
2	*Shafts*	To continue the rotation of the electric motor / drive to the impeller during operation	*Shafts*break and bend	• High vibration in axial and radial direction • Loose foundation bolts • Heat in the bearing housing	*Shafts*damaged so that the pump stops.
3	*Bearings*	To support and hold the load from the shaft so it can rotate.	*Bearings*too hot and broke	• Not enough lubricant • Too much lubricant • *Bearings*rusty	The pump is vibrating.
4	*Clutch*	To connect two shafts where one is the driving shaft and the driven shaft.	*Clutch*wear out	• Too little lubricant • Too much lubricant.	The pump suffers from vibration and misalignment.
5	*Mechanical Seals*	To prevent the entry and exit of liquid.	*Mechanical seals*have a leak	• Too fast spin • The seal surface is less smooth	The pump has a leak.

d. Component Cost Data

The following is data on component costs for centrifugal pumps:

Table 10. Component Cost Data and Company Total Cost

No	Component	Price (Rp/component)	total cost (Rp/year)
1	*Impeller*	400,000	2,000,000
2	*Shafts*	600,000	5,400,000
3	*Bearings*	700,000	16,800,000
4	*Clutch*	1,000,000	4,000,000
5	*Mechanical Seals*	950,000	2,850,000
Total		3,650,000	31,050,000

e. Labor Cost Data

The following is labor cost data obtained from the company:

Table 11. Labor Costs

No	Name	Cost (Rp/hour)
1	A worker	150,000
2	B worker	150,000
3	C worker	150,000
4	D worker	150,000
5	E worker	150,000
6	F worker	150,000
7	G worker	150,000
Total		1,050,000

1. Product Cost Data

The average price of PDAM tap water products is IDR 1,200/m3.

2. Energy Cost Data

The energy cost is IDR 26,752/kW for 1 pumping machine.

3. Data Loss Costs Due to Machine Downtime (Engine Idle)

Machine damage makes the company suffer losses. If it is known that the product price is IDR 1,200/m3 and the output produced is 1,500 liters/second, then the costs that must be borne are as follows:

Downtime Costs = product price x output
= IDR 1,200/m^3x 1.5 m3/second = IDR 1,800/second
= IDR 6,480,000/o'clock

The obtain the downtime percentage of centrifugal pump engine components in the table below:

Table 12. Sequence of Critical Components Based on Downtime Value

No	Component	Total Downtime (minute)	% Downtime	% Cumulative downtime
1	*Bearings*	3621	64.30%	64.30%
2	*Shafts*	1206	21.42%	85.72%
3	*Clutch*	324	5.75%	91.47
4	*Mechanical Seals*	279	4.96%	96.43
5	*Impeller*	201	3.57%	100%
Total		5631	100%	

Based on the table above, the sequence of critical components in a centrifugal pump machine is obtained with values*downtime*from the highest to the lowest, namely Bearings, Shafts, Couplings, Mechanical Seals and Impellers. The following is a pareto chart of downtime values:

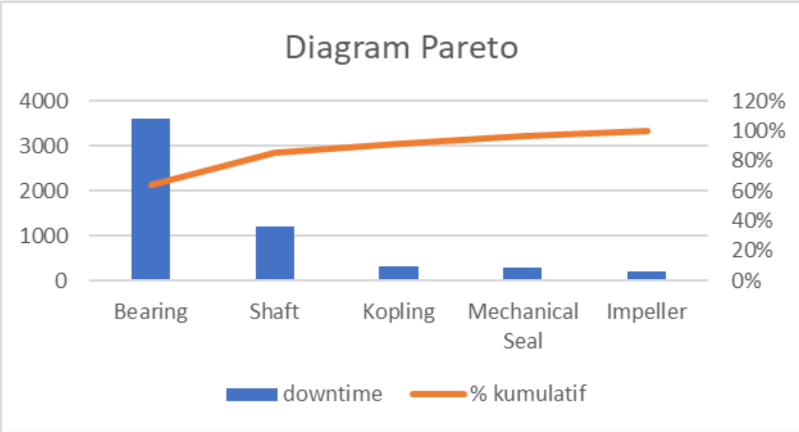

Figure 1. *Pareto Diagram on a Centrifugal Pump Machine*

f. Functional Block Diagrams (FBD)

Making a Functional Block Diagram aims to describe the work system of the machine such as the production process and the machine components involved in it and serves as information from the system about design and operation which is used as a reference for carrying out preventive maintenance actions in the future so that information parameters that cause system failure. The following is an illustration of a picture to show the work system on a centrifugal pump machine.

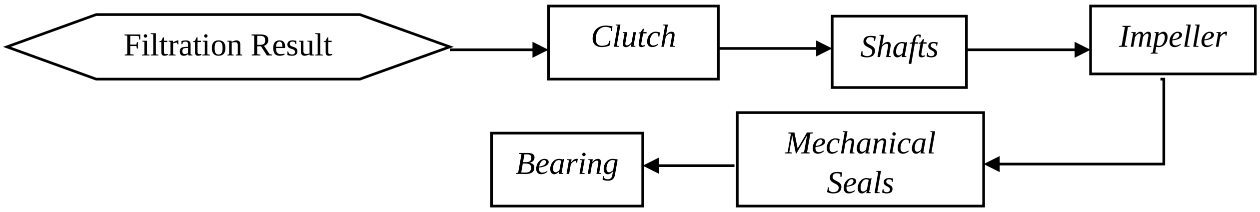

Figure 2. *Functional Diagram of a Centrifugal Pump*

g. Preparation of Faliure Mode and Effect Analysis (FMEA)

The previous stage has discussed the work system of the centrifugal pump, in the next stage will make a Failure Mode and Effect Analysis (FMEA) table which will later be used to identify function, functional failures, failure mode and failure effect of each centrifugal pump component, then it will be calculated the Risk Priority Number (RPN) value is based on the multiplication of Severity (S), Occurrence (O), Detection (D) and the highest value from the RPN calculation will be treated first. The preparation of the Failure Mode and Effect Analysis (FMEA) table is carried out based on the data in table 4.9.

Following are the standard Severity (S), Occurrence (O), and Detection (D) values for each component:

- The Impeller component gets an S value of 8 because it is not capable of treating water, an O value of 3 because of the frequency of damage 5-10 per 7200 hours of use, a D value of 3 because of a high chance of being detected.
- The Shaft component gets an S value of 10 because the engine is not working, an O value of 3 because of the frequency of damage 5-10 per 7200 hours of use, a D value of 2 because of a very high chance of being detected.

- The Bearing Component gets an S value of 6 because the pump experiences vibration, an O value of 6 because of the frequency of damage 21-25 per 7200 hours of use, a D value of 3 because of a high chance of being detected.
- The clutch component gets an S value of 6 because the pump experiences vibration and misalignment, an O value of 2 because the frequency of damage is less than 5 per 7200 hours of use, a D value of 3 because of a high chance of being detected.
- The Mechanical Seal component gets an S value of 7 because the pump has a leak, an O value of 2 because the frequency of damage is less than 5 per 7200 hours of use, a D value of 2 because of a very high chance of being detected.

Table 13. Failure Mode and Effect Analysis of Centrifugal Pumps

*RCM*INFORMATION WORKSHEET											
Component	*function*		*Functional Failure*		*Failure Modes* (Cause of failure)		*Failure Effect* (what happens if it fails)	S	O	D	RPN
Impeller	1	To convert the kinetic energy of the pump into velocity energy	A	Reduced water discharge	1	*Impeller*too hot and worn out.	The pump is not capable of treating water	8	3	3	72
Shafts	1	To continue the rotation of the electric motor to the impeller during operation	A	*Impeller*not working optimally	1	High vibration	The pump is unable to function	10	3	2	60
Bearings	1	To support and hold the load from the shaft so it can rotate	A	The shaft experienced a slowdown in performance	1	*Bearings*rusty	The pump is vibrating	6	6	3	108
Clutch	1	To connect two shafts where one is the driving shaft and the driven shaft	A	The two shafts do not lie on one axis.	1	Lubricant too much/little	The pump suffers from vibration and misalignment	6	2	3	36
Mechanical Seals	1	To prevent the entry and exit of liquid	A	Liquid gets into other components	1	The seal surface is less smooth	The pump has a leak	7	2	2	28

Information:
S : *Severity*
O : *Occurrence*
D : *Detection*

The table above consists of:

1. *Function* used to describe the function of the component being analyzed.
2. *Functional failure* used to determine the failure that occurs in the component being analyzed so that the component cannot function properly.

3. *Failure modes* used to identify the causes of failures that occur in the component being analyzed.
4. *Failure effects* used to identify the effect or impact caused by a component malfunction.
5. *Severity* used to determine the value of how much the impact or intensity of events affects the output of the process.
6. *Occurrence* used to determine the value of the frequency of damage that occurs.
7. *Detection* used to determine the value in detecting damage that occurs.
8. *Risk Priority Number* used to determine the risk priority number obtained from the multiplication of severity, occurrence, and detection with the formula RPN = S x O x D.

h. Determination of the Distribution of Damage

In determining the distribution of damage it is divided into 2 tests, namely the test of the distribution of time between damages and the distribution of the duration of repairs in Table 3-7 carried out with Minitab 18 software. For the selection of the type of distribution based on the smallest Anderson-Darling value. The output of the Minitab 18 software as a result of testing the distribution of time between breakdowns and the distribution of repair times can be seen in Appendix B and Appendix C.

The following is a recapitulation table of test results for the distribution of time between failures (Tf) based on the smallest Anderson-Darling value with Minitab 18 software, namely as follows:

Table 14. Test Results of Distribution of Time Between Damages

No	Component	Information	Distribution	Parameter	
				β (shapes)	η*(Scale)*
1	*Impeller*	Tf (Time Failure)	*Weibull*	4.50	1936,31
2	*Shafts*	Tf (Time Failure)	*Weibull*	3.96	984.88
3	*Bearings*	Tf (Time Failure)	*Weibull*	5,27	393.56
4	*Clutch*	Tf (Time Failure)	*Weibull*	4.51	2349,24
5	*Mechanical Seals*	Tf (Time Failure)	*Weibull*	9.90	2099,53

Source: Data processing

After obtaining the distribution and parameters of each distribution on the test results of the distribution of time between damages, then the calculation is carried out*Mean Time To Failure*(MTTF) using the formula $=\eta\Gamma(1+\ ).\frac{1}{\beta}$

Example of MTTF calculation on Impeller:

Is known:η=1936,31,β=4.50,Γ (Gamma function table)

MTTF $=\eta\Gamma(1+\ ) = 1936.31\ \Gamma(1+\ )\frac{1}{\beta}\frac{1}{4{,}50}$

$=1936.31\ \Gamma\ (1.22) = 1936.31\ (0.9311)$

=1768,064 hours

Table 15. MTTF (Mean Time to Failure) Value

No	Component	MTTF (hours)
1	*Impeller*	1768,064
2	*Shafts*	892.6952

3	*Bearings*	363.5432
4	*Clutch*	2145,115
5	*Mechanical Seals*	1997,766

Next, the test value of the repair time distribution (Tr) is generated with *software* minitab 18 based on the smallest Anderson-Darling value as follows:

Table 16. Test Results of Repair Time Distribution

No	Component	Information	Distribution	Parameter	
				β (shapes)	η*(Scale)*
1	*Impeller*	Tr (Time Repair)	*Weibull*	13.85	41.71
2	*Shafts*	Tr (Time Repair)	*Weibull*	15,33	138.45
3	*Bearings*	Tr (Time Repair)	*Weibull*	28.93	153,64
4	*Clutch*	Tr (Time Repair)	*Weibull*	15.87	83,66
5	*Mechanical Seals*	Tr (Time Repair)	*Weibull*	27,25	95.18

Source: Data processing

After obtaining the distribution and the parameters of each distribution on the results of testing the distribution of the repair time, then the calculation is carried out*Mean Time To Repair* (MTTR) using the formula $=\eta\Gamma(1+).\frac{1}{\beta}$

Example of MTTR calculation on Impeller:

Is known:η=41.71,β=13.85,Γ (Gamma function table)

MTTR $=\eta\Gamma(1+) =\frac{1}{\beta}41.71\Gamma\ (1+)\frac{1}{13{,}85}$

$= 41.71\Gamma\ (1.07) =41.71(0.96415)$

$=40.2147$ minutes = 0.670245 hours

Table 17. Value of MTTR (Mean Time to Repair)

No	Component	MTTR (hours)
1	*Impeller*	0.670245
2	*Shafts*	2.235368
3	*Bearings*	2.518544
4	*Clutch*	1.350746
5	*Mechanical Seals*	1.560238

i. Determination of Maintenance Intervals

In determining the appropriate maintenance interval for each component, it is necessary to parameterize the appropriate distribution of time between breakdowns, replacement costs due to damage and replacement costs due to maintenance on centrifugal pump engine components.Before determining the maintenance interval, the cost calculation is carried out as follows:

j. Cost of Component Replacement due to Maintenance (C_M)

These costs include operator labor, maintenance or mechanical labor costs and component prices. The formula used to calculate replacement costs due to maintenance is:

C_M= [(Mechanical costs (hours) x MTTR (hours)] + Component prices

Example of calculating replacement costs due to maintenance on Impeller components based on table 4.10, table 4.11 and table4.15 is:

C_M = [Mechanical fee x MTTR] + Component price

=[Rp150,000x 0.672045] +Rp 400,000

= IDR 500,536.7

So in the same way, the calculation results of the component replacement costs due to maintenance are obtained which can be seen in the table below:

Table 18. Replacement Cost Due to Maintenance (C_M)

No	Component	Price (IDR)	Mechanical Fee (Rp/hour)	MTTR (o'clock)	CM (IDR)
1	*Impeller*	400,000	150,000	0.670245	500,536.7
2	*Shafts*	600,000	150,000	2.235368	935,305.1
3	*Bearings*	700,000	150,000	2.518544	1,077,782
4	*Clutch*	1,000,000	150,000	1.350746	1,202,612
5	*Mechanical Seals*	950,000	150,000	1.560238	1,184,036

k. Cost of Component Replacement due to Damage (C_F)

This replacement cost includes operator costs, mechanical costs, downtime costs and component prices where the entire cost is a loss caused by component damage. The formula used to calculate the cost of replacement due to damage is:

C_F= [((Mechanical costs (hours) + Downtime costs (hours)) x MTTR (hours)] + component prices.

Example of calculating the cost of replacement due to damage to the Impeller componentbased on table 10, 11 and table 15 is:

C_F=[(Rp150,000 + 6,480,000) x 0.670245] +Rp 400,000

= IDR 4,843,724

So in the same way the calculation results of the cost of component replacement due to maintenance are obtained which can be seen in the table below:

Table 19. Component Replacement Costs due to Damage (C_F)

No	Component	Price (IDR)	Mechanical Fee (Rp/hour)	Downtime Fee (Rp/hour)	MTTR (o'clock)	CF (IDR)
1	*Impeller*	400,000	150,000	6,480,000	0.670245	4,843,724
2	*Shafts*	600,000	150,000	6,480,000	2.235368	15,420,487
3	*Bearings*	700,000	150,000	6,480,000	2.518544	17,397,945
4	*Clutch*	1,000,000	150,000	6,480,000	1.350746	9,955,449
5	*Mechanical Seals*	950,000	150,000	6,480,000	1.560238	11,294,379

l. Calculating Maintenance Intervals (TM)

After obtaining component replacement costs due to damage ($C_F C_M$), replacement costs due to maintenance () and parameters that are in accordance with distribution testing, the next step is to calculate the optimal maintenance interval (TM). The formula used to calculate the maintenance interval (TM) isas follows:

$$TM = \eta\left(\frac{CM}{CF-CM} \cdot \frac{1}{\beta^{-1}}\right)^{\frac{1}{\beta}}$$

Based on the calculation resultsreplacement costs due to maintenance (), component replacement costs due to damage () in table 4.16 and table 4.17,$C_M C_F$Test Results Distribution of time between damage in table 4.12 thenmaintenance interval (TM) can be calculated as follows

Example of maintenance interval calculation (TM) on *Impeller*:

$$TM = \eta\left(\frac{CM}{CF-CM} \cdot \frac{1}{\beta^{-1}}\right)^{\frac{1}{\beta}}$$

$$=442{,}510\left(\frac{\text{Rp } 10.242.837}{\text{Rp } 21.637.526 - \text{Rp } 10.242.837} \cdot \frac{1}{0{,}676^{-1}}\right)^{\frac{1}{0{,}676}}$$

= 397,778o'clock

The summary of the results of calculating the maintenance interval for each component can be seen in the following table 20.

Table 20. Maintenance Intervals

No	Component	β(shapes)	η (Scale)	CM (IDR)	CF(IDR)	TM (hour)
1	*Impeller*	4.50	1936,31	500,536.7	4,843,724	1673
2	*Shafts*	3.96	984.88	935,305.1	15,420,487	698
3	*Bearings*	5,27	393.56	1,077,782	17,397,945	322
4	*Clutch*	4.51	2349,24	1,202,612	9,955,449	2.113
5	*Mechanical Seals*	9.90	2099,53	1,184,036	11,294,379	2,131

m. RCM II Decision Worksheet

After analysis *Failure Mode and Effect Analysis* (FMEA) engine components centrifugal pumps listed in table 13 and it is known that the value of the maintenance interval (TM) on the centrifugal pump machine is contained in table 18, so the next step is to make the RCM II Decision Worksheet table. The RCM II Decision Worksheet is used to find the right type of maintenance task (maintenance task) that has the possibility to overcome each failure mode. Based on the table below, we can see the RCM II Decision Worksheet on a centrifugal pump machine.

The way to fill in the RCM II Decision Worksheet table is as follows: For components in centrifugal pumps, in order to fill in the Information Reference column for centrifugal pump components, we must first look at table 13 Failure Mode and Effect Analysis (FMEA). The Information Reference column consists of F (function), which is the component function (which is analyzed), FF (failure function), which is the failure function, and FM (failure mode), which is the cause of the function failure. F value of 1 means that the Impeller component has 1 function, namely to convert the kinetic energy of the pump into speed energy, FF value of A means that the Impeller component has 1 malfunction, namely reduced water discharge, FM has a value of 1 meaning the Impeller component has 1 cause of malfunction, namely the impeller is too hot and worn out. The Consequences evaluation column consists of H (Hidden Failure), S (Safety), E (Environmental) and O (Operational). H value N (No) means Impeller overheating and wear damage including predictable failure, S value N (No) means damage to the Impeller does not endanger the safety of employees, E value N (No) means damage to the Impeller does not endanger the surrounding environment, O value (Y) means Impeller damage has an impact on product output. In the Proactive Taks column, it consists of H1/S1/O1/N1 to record whether *Scheduled On-Condition Task* can be used to minimize the occurrence of failure mode, H2/S2/O2/N2 to record whether Scheduled restoration task can be used to prevent failure, and H3/S3/O3/N3 to record whether scheduled discard task can be used to prevent failure. H1/S1/O1/N1 has a value of N (No) meaning that inspection activities cannot prevent damage to the impeller wear. H2/S2/O2/N2 has a value of Y (Yes) meaning that the item's capability recovery action is a way to prevent further damage to the Impeller. H3/S3/O3/N3 has a value of N (No) means Scheduled discard task. The action of replacing a worn impeller is a good action to deal with damage to the Roll Table but will require a greater cost compared to repairing existing items. The Default Action column which includes H4/H5/S4 is empty because the action in the Proactive Taks column has been able to overcome damage to the Impeller. The Proposed Task column contains means that the proposed task to deal with damage to the Impeller is a scheduled restoration task, namely repairing the Impeller. The optimal maintenance interval for caring for centrifugal pumps on the Impeller component is every 1,673 hours and the mechanic is responsible for carrying out repairs to the damaged Impeller.

The summary of the results of the RCM II decision worksheet is in table 21 below:

Table 21. RCM II Decision Worksheet

RCM II DECISION WORKSHEET																
Component	***Informationreference***			***Consequence evaluation***				**H1 S1 O1**	**H2 S2 O2**	**H3 S3 O3**	***Default actions***			***proposed task***	**Interval (TM) (hours)**	***Can be done be***
	F	**FF**	**FM**	**H**	**S**	**E**	**O**	**N1**	**N2**	**N3**	**H4**	**H5**	**S4**			
Impeller	1	A	1	Y	N	N	Y	N	N	Y				*Scheduled discard task.*the act of replacing hot and worn impellers is the best way to deal with damage to the impeller.	1673	Mechanic
Shafts	1	A	1	Y	N	Y	Y	N	Y	N				*Scheduled restoration task*the item's capability recovery action is able to prevent damage to shafts that have high vibrations.	698	Mechanic
Bearings	1	A	1	Y	N	N	Y	N	Y	N				*Scheduled restoration task*the item's ability recovery action can prevent damage to rusty Bearings.	322	Mechanic
Clutch	1	A	1	N	N	N	Y	N	Y	N				*Scheduled restoration task*the action of recovering the ability of the item is able to prevent damage to the clutch from misalignment.	2.113	Mechanic
Mechanical seals	1	A	1	Y	N	Y	Y	N	N	Y				*Scheduled discard task.*the act of replacing a mechanical seal that is leaking is the best way to deal with damage to the mechanical seal	2,131	Mechanic

j. Total Costs Based on the Life Cycle Cost (LCC) Method

*Total Life Cycle Cost*is the calculation of the total cost from the initial purchase cost to the end of the life of the machine. LCC is obtained by adding up the total sustaining costs which consist of operating costs, maintenance costs, shortage costs, and acquisition costs which consist of purchasing costs and population costs. The results of the overall LCC can be seen in the table.

In order to calculate the Total Life Cycle Cost, the value of the sustainable costs is required in Table 4.27 and the acquisition cost in Table 4.34. An example of calculating the total Life Cycle Cost for Year 1 with the number of mechanics (M) = 6 is as follows

Total LCC = sustaining cost + acquisition cost

=Rp. 1,388,820,800 + Rp. 993,572,333

= Rp. 2,382,393,133

Table 22. Determination of Machine Age, Number of Mechanics and Total Cost Based on the Life Cycle Cost Method

Age (n)	Mechanical Number	
	3	6
1	Rp. 2,073,554,232	Rp. 2,382,393,133
2	Rp. 1,650,251,258	Rp. 1,974,530,304
3	Rp. 1,537,415,915	Rp. 1,877,690,197
4	Rp. 1,524,766,166	Rp. 1,882,278,435
5	Rp. 1,515,507,735	Rp. 1,890,892,365
6	Rp. 1,526,536,516	Rp. 1.920.687049
7	Rp. 1,549,697,192	Rp. 1,964,068,151
8	Rp. 1,581,022,983	Rp. 2,015,565,788
9	Rp. 1,618,424,367	Rp. 2,074,689,516
10	Rp. 1,660,657,225	Rp. 2,139,730,580
11	Rp. 1,707,022,490	Rp. 2,210,044,009
12	Rp. 1,757,025,259	Rp. 2,285,191,479
13	Rp. 1,810,460,598	Rp. 2,365,028,174
14	Rp. 1,867,112,624	Rp. 2,449,400,018
15	Rp. 1,926,067,944	Rp. 2,537,462,933

From the table above it can be seen that the total life cycle cost with the smallest value is found in the number of mechanics (M) = 3, year (n) = 5 years with a total cost of IDR 1,515,507,735

4.2 Discussion

From the LCC (Life Cycle Cost) calculation above, it can be seen based on table 4.20, it is found that the smallest cost value is in year (n) = 5 with the number of mechanics (M) = 3 with the result of calculating a total cost of Rp. 1,515,507,735. So, it can be concluded that TC2 < TC1 with these results, the proposed method in this study is accepted.

V. Conclusion

1. The maintenance interval for each centrifugal pump component is for the Impeller of 1,673 hours by selecting the Discard task, Shaft of 698 hours by selecting the scheduled restoration task, bearing by 322 hours by selecting the scheduled restoration task,

coupling by 698 hours by selecting the scheduled restoration task, Mechanical seal for 2,131 hours with the selection of the scheduled discard task.

2. The results of the calculation of the total cost of Rp. 1,515,507,735 as TC2 with a total company cost of IDR 1,600,000,000. So, it can be concluded that TC2 < TC1.

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