International Journal of Marine Engineering Innovation and Research, Vol. 9(1), March. 2024. 208-217
(pISSN: 2541-5972, eISSN: 2548-1479)

Optimizing Small Excavator Maintenance Activity Planning Using the Reliability-Centered Maintenance (RCM) Method II

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(Received: 22 January 2024 / Revised: 26 February 2024 /Accepted: 9 March 2024)

***Abstract*— Construction activities include the stages of construction, operation, maintenance, demolition, and rebuilding of a building. One of the construction activities in Indonesia is the construction of double-track railways. In the double-track railway construction project, there is a small excavator A which often fails. The excavator is used for excavation, land stripping, and embankment work. Failures that occur can disrupt construction implementation and can result in the company experiencing losses. Maintenance activities in the construction company that is the research location have a maintenance schedule, namely every 3 months and every 6 months based on the manual book, without adjusting the condition of the equipment. Therefore, it is necessary to analyze excavator components so that appropriate maintenance is known. RCM II is a maintenance evaluation method so that system components run well and according to the expected function by determining a maintenance action that must be carried out based on the characteristics of machine use so that maintenance activities run optimally. This research uses the RCM II method to determine the maintenance schedule, as well as the FMEA method. The FMEA results show 43 failure modes. RCM II decision worksheet analysis showed that 8 components had scheduled discard task maintenance they are hydraulic hose components, a hydraulic pump, a track roller, a carrier roller, an oil filter, a diesel filter, a boom cylinder, a front idler, 3 components had scheduled restoration task maintenance for fuse box components, air filter, and an arm cylinder. 1 component, track shoe components had scheduled on-condition task maintenance.**

Keywords— Critical component, Excavator, Failures, FMEA, RCMII

I. Introduction

In implementing construction projects, heavy equipment is needed to assist with earthworks and various other construction areas. Heavy equipment is mechanical equipment that aims to facilitate human work in carrying out a job so that the work process becomes lighter, and the time required is shorter [1]. One of the heavy equipment used in the double-track railway construction project is an excavator. An excavator is heavy equipment that has the function of digging and dredging soil. In this research activity, the excavator has the function of carrying out stripping, excavation, and embankment work. In stripping and excavation work, the way an excavator works is to dig up the soil and then move it into a truck. In embankment work, the way an excavator works is to level the soil material on the road [2]. There are 5 excavators used in the double-track railway construction project. The excavators are small excavator A, small excavator B, mid-size excavator, medium excavator A, and medium excavator B. Smallexcavator A is the type of excavator that experiences the most failures. Failures that occur can disrupt construction implementation and can result in the company experiencing losses. Maintenance activities in the construction company that is the research location have a maintenance schedule of 3 months and 6 months based on the manual book, without adjusting the condition of the equipment.

Maintenance is a combination of all technical, administrative, and managerial actions on equipment or machinery aimed at maintaining it or returning it to a state in which it can perform its required functions [3]. Reliability Centered Maintenance (RCM) II is a maintenance evaluation method so that each physical item or system can run well and according to the function expected by the user by determining a maintenance action that must be carried out so that maintenance activities run optimally [4]. Viewed from the Occupational Safety and Health (K3) aspect, the RCM II method includes an analysis of one method of hazard identification and risk assessment, namely FMEA (Failure Modes and Effects Analysis). This analysis aims to assist researchers in carrying out a breakdown of component types, component functions, component failures, and component failure modes. The results of the FMEA analysis are then used in the RCM II decision worksheet where the maintenance interval for each component will be known [5]. So this research aims to plan maintenance activities using RCM in construction companies.

Based on the background that has been explained, this research aims to find out the results of failure identification and risk assessment on small excavator A in a construction company using the FMEA method and to find out the results of determining proposed tasks and maintenance scheduling intervals using the RCM II method on small excavator A located in a construction

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company. The limitations of the problem in this research are that the excavator used as the research object is small excavator A which has a bucket capacity of 0.2 m3 - 0.4 m3, a maximum working weight of 1.7 tons, and was built in 2018, data on excavator damage and repairs are data for January 2019 – December 2022, determining data distribution using statistical data processing software.

II. METHOD

A. Data Collection Stage

This stage is carried out by collecting data that will be used in research. There are 2 data needed, namely primary data and secondary data. In carrying out this research, primary data is required including component function data, failure data, causes of failure, and the consequences of failures that occur. This data was obtained through a discussion process together with expert judgment to create FMEA (Failure Mode and Effect Analysis). Secondary data required includes data on the time between excavator failures (Time To Failure/TTF), the time between excavator machine repairs (Time To Repair/TTR), the price of excavator components, and costs due to damage.

B. Data Processing Stage

a. Functional Block Diagram (FBD)
Creating a Functional Block Diagram (FBD) serves to describe the workflow system of the excavator when operating.

b. Failure mode and Effect Analysis (FMEA)
In the RCM II method, there is an information worksheet. Making FMEA in RCM II functions to identify failures that occur in excavators by providing a risk assessment using RPN (Risk Priority Number).

c. RCM II Decision Worksheet
This stage is carried out by determining appropriate maintenance activities using the RCM II Decision Diagram. At this stage, several questions must be answered to fill in the RCM II Decision Worksheet table. Preparation of RCM II Decision Worksheet based on failure data.

d. Determining Maintenance Intervals
At this stage, a distribution test is carried out on the time between failures (TTF) and repair time (TTR) on the excavator with the help of statistical data processing software. Next, the data is processed to determine the optimal maintenance time interval in terms of minimum costs.

III. RESULTS AND DISCUSSION

A. Functional Block Diagram (FBD)

The first stage in implementing the RCM II method is creating an FBD (Functional Block Diagram). A functional Block Diagram (FBD) or block diagram is a flow diagram that describes the relationship and work flow between component functions that form a system and clarifies the scope of analysis so that the process of analyzing functions and functional failures can be carried out easily [6]. This diagram acts as a medium that describes the relationship between sub-system functions, which form a unified workflow system for each component of the excavator's heavy equipment in carrying out the movement process. Thus, this diagram facilitates functional analysis and identification of functional failures. In the process, the input and output of each sub-system variable or component can be connected to other blocks via connecting lines. Based on the results of discussions with expert judgment, it is known that small excavator A has 6 subsystems as follows:

1. Electrical Sub-system: includes the electrical system that supports operations, control systems, and other systems on the excavator [7].
2. Control Sub-system: The system used by the operator to control and operate the excavator [8].
3. Hydraulic Sub-system: a system that utilizes hydraulic pressure to move excavator components [9].
4. Engine Sub-system: the system that operates the diesel engine to convert the heat energy of the fuel into motion energy [10].
5. Structural Sub-system: a system that provides strength, stability, and support for the excavator machine and work components.
   a. Lower Structure sub-system (undercarriage and blade): lower components that act as heavy equipment carriers.
   b. Upper Structure sub-system: components at the top of the excavator [11].

Figure 1 below is an Excavator Functional Block Diagram describing the relationships and work flow of all excavator components. The center swivel joint component is located between the undercarriage (lower structure) and upper structure, which plays an important role in the mobility and maneuverability of the excavator. The center swivel joint also functions as a link between the hydraulic lines in the lower structure and the excavator's upper structure. In the process of rotating movement (swing), the hydraulic fluid flows through the center swivel joint, thereby preventing twisting or excessive rotation of the hydraulic hose. The swing motor is a hydraulic motor that is responsible for producing rotating movement (swing) in the excavator upper structure. Swing motor allows the excavator to rotate 360 degrees.

Travel motor is a hydraulic motor that drives the excavator undercarriage to move forward and backward. The travel motor receives power from the hydraulic system and transmits it to the final drive. The final drive is the component that connects to the sprocket and drives the track chain. The rotary movement of the final drive is transmitted through the sprockets to move the track chain and track shoes. Track links form a series of track chains that move along the undercarriage. The links in the track chain are connected to each other and ensure the track chain remains stable when moving.

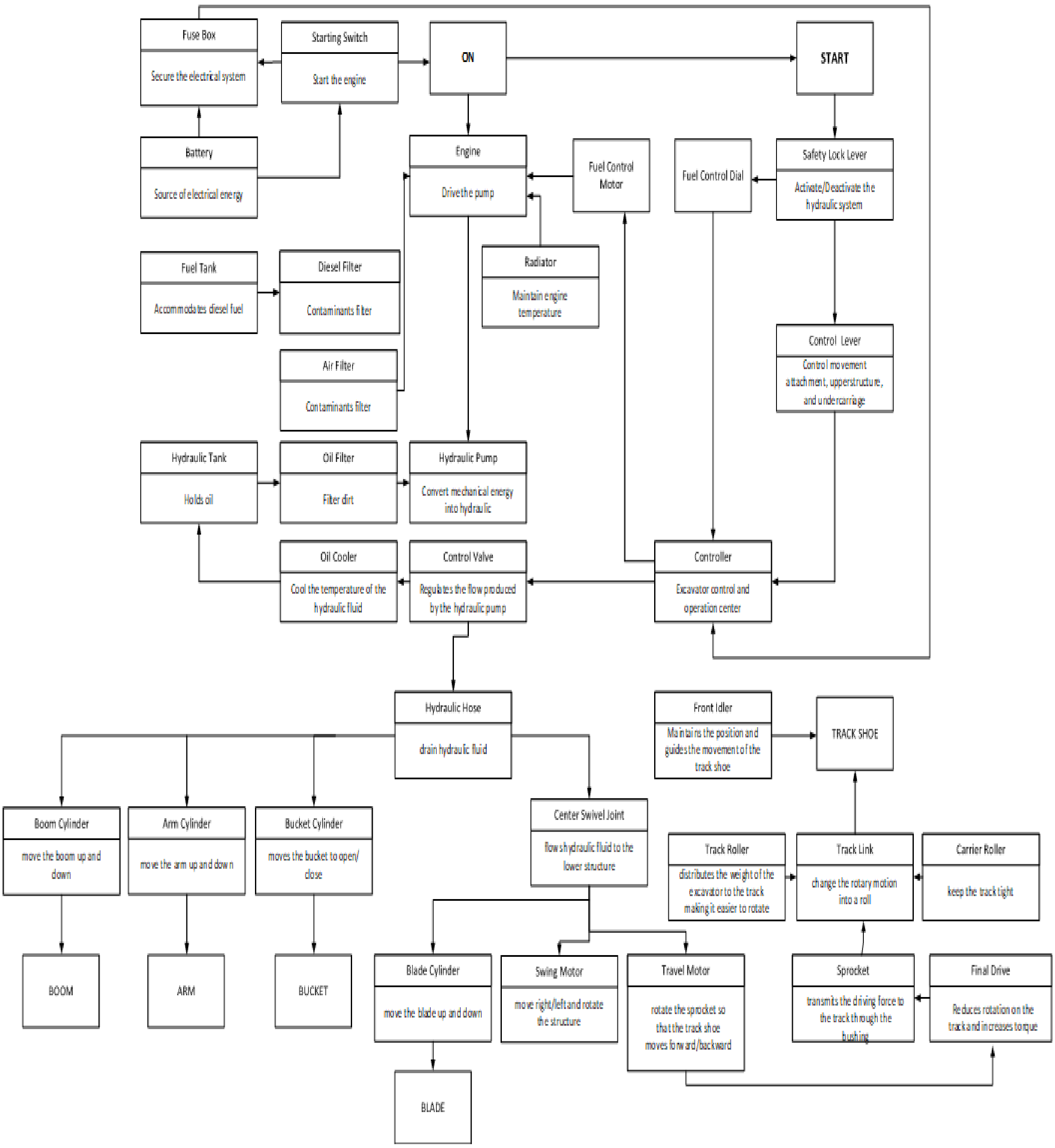

Figure. 1. Functional Block Diagram Excavator

The front idler is a roll wheel located at the front of the undercarriage. The front idler serves as a support and guide for the track chain. This helps direct and distribute the load evenly across the track chain. Track shoes are components that are connected to the track chain and are in direct contact with the ground surface. Track shoes consist of several plates connected by shoe bolts to form a circuit. The track shoe moves together with the track chain and is supported by a roller component. There are 2 rollers, namely the track roller and carrier roller which function as supporting components for the track link (track chain). A track roller (bottom roller) is a rolling wheel located under the track chain. Track rollers help distribute the load evenly on the track chain and minimize friction when the undercarriage moves. Meanwhile, the carrier roller is a rolling wheel that is located above the track chain. The carrier roller functions to keep the track tight [12]. All of these components work together in the excavator undercarriage system to provide support, movement, and stability to the machine.

B. Failure mode and Effect Analysis (FMEA)

The second stage after describing the system workflow function for each component is creating a Failure Mode and Effect Analysis (FMEA), which functions to identify failures experienced by excavator heavy equipment components. FMEA is a method that identifies and analyzes the causes of failure and the impacts caused by the failure [13]. FMEA or RCM II is referred to as RCM II Information Worksheet. The qualitative data used is the type of component, data on the function of the machine component (function), the cause of damage (functional failure), and the damage effect (failure effect) of each component. Making FMEA is based on the components contained in the Functional Block Diagram, namely, there are 6 sub-systems consisting of 37 components.

The next step after identifying excavator component failures is determining risk priorities or assessing the risk of malfunctioning of each component using the Risk Priority Number (RPN).

Risk assessment is based on three assessment categories, namely severity, occurrence and detection. The RPN assessment is made with the approval of the relevant expert judgment parties, namely the excavator operator and HSE Officer. The following is the Excavator FMEA (Failure Mode and Effect Analysis) which can be seen in Table 1.

Based on the results of the Failure Mode and Effect Analysis (FMEA) in Table 1, it can be seen that several RPN (Risk Priority Number) values tend to be high. Determination of severity (S), occurrence (O), and detection (D) values is based on the results of discussions with related expert judgment. The occurrence (O) value is based on excavator failure data over a period of 4 years. Meanwhile, the severity (S) and detection (D) assessments are qualitative in nature based on brainstorming with excavator operators who have worked for 13 years. Track shoe components with loose shoe bolt failure mode result in downtime of more than 6 hours so they have a severity value (S) of 4, failure is almost certain to occur because they occur more than 5 times each year so they have an occurrence value (O) of 5, and failures are rarely detected so the value detection (D) 3. The total RPN of the track shoe component with the failure mode of the shoe bolt removed has a value of 60. The highest RPN value is 60 for the track shoe component with the failure mode of the shoe bolt removed. Several other components that have a high RPN value are a hydraulic pump with a damaged failure mode, the regulator seal kit has an RPN value of 32, an oil filter with a damaged failure mode has an RPN of 32, a fuse box with a broken failure mode fuse has an RPN of 24, a hydraulic hose with failure mode leak has RPN 24, arm cylinder with failure mode worn or damaged cylinder rod has RPN 24, boom cylinder with failure mode worn or damaged boom seal has RPN 24, air filter with damaged failure mode has RPN 24, diesel filter with failure mode damaged has an RPN of 24, a track roller with a damaged failure mode has an RPN of 24, a carrier roller with a damaged failure mode has an RPN of 24, a front idler with a damaged failure mode has an RPN of 24, and a radiator with a damaged failure mode has an RPN of 20. These components have experienced failure.

TABLE 1.
FMEA EXCAVATOR

System: Small Excavator A						***Date :* May 2023**						
***Sub-System:* electrical, control, hydraulic, engine, lower structure, and upper structure**												
No	***Equipment***	***Function***		***Functional Failure***		***Failure Mode***		***Failure Effects***	***S***	***O***	***D***	***RPN***
01. Electrical Sub-System												
1	*Fuse box*	1	Securing the electrical system	A	Failed to secure the electrical system	1	The fuse has blown	Loss of function of some systems	4	3	2	24
02. Control Sub-System												
2	*Safety lock lever*	1	Activates/deactivates the hydraulic system	A	Cannot activate the hydraulic system	1	stuck fast	The hydraulic system cannot work	4	1	2	8

03. Hydraulic Sub-System												
3	*Hydraulic pump*	1	Converts mechanical energy into hydraulic energy in the form of flow and pressure	A	Hydraulic pump pressure does not match demand	1	Hydraulic pump overheating	Reduced performance and instability in attachment movement (boom, arm, bucket and blade)	3	1	3	9
						2	*The regulator seal kit is worn/damage d*	Leaks and drops in hydraulic pressure produced by the hydraulic pump	4	2	4	32
4	Oil filter	1	Filters engine oil and keeps it clean from dirt particles, fine metals and other contaminants	A	Failing to filter and keep the oil clean from contaminants	1	Damaged oil filter	There are contaminants in the engine and can damage the engine	4	4	2	32
5	Hydraulic hose	1	Flows hydraulic fluid	A	The fluid does not flow properly	1	Leaking	Excavator movement is not optimal	4	3	2	24
6	*Boom cylinder*	1	Moves the boom up/down	1	Cannot move boom	1	*Damaged boom cylinder seal*	Oil seepage in the boomcylinder area, damage to the piston and cylinder rod	3	2	2	12
						2	The cylinder rod is worn or damaged	Decreased boom component performance	4	1	2	8
7	*Armcylinder*	1	Move the arm up/down	1	Cannot move arm	1	*Armcylinder seals are worn or damaged*	Oil seepage in the armcylinder area, damage to the piston and cylinder rod	3	1	2	6
						2	The cylinder rod is worn or damaged	Decreased performance of arm components	4	3	2	24
						3	The cylinder rod is worn or damaged	Decreased performance of blade components	4	1	2	8
8	Air Filter	1	Filters air contaminants	A	Fails to filter air contaminants	1	Air filter damaged	There are contaminants in the machine and damage the machine	4	3	2	24
9	Diesel filters	1	Filters dirt, sediment, and other contaminants contained in fuel	A	Failing to filter and keep diesel fuel clean from contaminants	1	Diesel filter damaged	There are contaminants in the engine and can damage the engine	4	3	2	24
10	Radiator	1	Maintains engine temperature within a safe operational range by transferring heat from the engine to the air	A	Engine temperature is not within safe operational range	1	Damaged radiator	Damage to machine components resulting in downtime	5	1	4	20
04. Engine Sub-System												
11	*Engine (diesel engine)*	1	Drives the hydraulic pump	A	The pump cannot be moved	1	Engine overheating	Reduced engine performance	3	1	4	12
05.Sub-Sistem *Lower Structure*												
12	*Track* roller *(bottom roller)*	1	Distributes the unit weight to the track making it easier to rotate the track	A	Failing to distribute the excavator weight to the track	1	*The track roller is damaged*	Track roller operation is not optimal	4	2	3	24
13	*Carrier roller*	1	Holds the rolled part of the track shoe from bending downwards so that the track shoe remains tight	A	*The track is loose*	1	Worn-out	Track shoe operation is not perfect	4	2	3	24
14	*Track* shoe	1	Excavator base	A	The excavator's movement is not perfect	1	*Broken track shoe*	*The track shoe is detached from the frame mount*	3	1	2	6
15	Front idler	1	As a support wheel that maintains the position and guides the movement of the trackshoe in place	A	Failing to maintain position and guide the movement of the trackshoe in place	1	*Front idler* damaged	*the front idler does not rotate smoothly or experiences abnormal vibration*	4	3	2	24
06. Sub-System Upper structure												
16	*Boom*	1	Swing the arm so that the bucket's range of motion can be greater	1	Unable to swing arm	1	*The boom is cracked or broken*	Decreased boom performance, boom cannot be used	4	1	1	4

C. *RCM II Decision Worksheet*

Components that are analyzed using the RCM II Decision Worksheet are critical components and components that have experienced failure. Components that are supported by the availability of data on failures that have occurred, these components are analyzed further through the RCM II Decision Worksheet filling stage to identify the appropriate type of maintenance activity/proposed task [5]. The columns in the RCM II Decision Worksheet are answered using the RCM II Decision Diagram. The total excavator components analyzed by the RCM II Decision Worksheet were 12 components.

The components carried out by RCM II analysis are hydraulic hoses, hydraulic pump, boom cylinder, arm cylinder, diesel filter, oil filter, air filter, fuse box, track shoe, carrier roller, front idler, and track roller. These components have supporting data, namely failure data for the period January 2019 – December 2023. In determining the RCM II Decision Worksheet table, first answer the RCM II Decision Diagram questions and then after knowing the appropriate type of maintenance for each component, carry out data processing. The following are the results of data distribution testing obtained from excavator failure data which can be seen in table 2.

Based on the results of analysis using statistical data processing software as in table 4.5, it is known that the results of Time To Failure (TTF) data distribution produce the Weibull 2 distribution type, namely hydraulic hose, hydraulic pump, fuse box, track roller, track shoe, oil filter, filter diesel, air filter, boom cylinder, and arm cylinder. Weibull distribution type 2 produces Beta (β) and Eta (η) parameters. The TTF data that produces the Normal distribution type is the carrier roller and front idler components. The normal distribution type produces the parameters Beta(β), Eta (η), Mean (μ), and Std (σ). The results of data distribution for Time To Repair (TTR) which is of the Weibull 2 type, namely the air filter and arm cylinder components. TTR data of the Weibull 3 type includes hydraulic hose components, fuse box, track roller, carrier roller, track shoe, oil filter, diesel filter, and boom cylinder. Weibull distribution type 3 produces Beta (β), Gamma (γ), and Eta (η) parameters.

TABLE 2.
DATA DISTRIBUTION TEST RESULTS

No	Component	Failure Mode	Annotation	Distribution	Beta(β)	Eta (η)	Gamma (γ)	Mean (μ)	Std(σ)
1	Hydraulic Hose	Leaking hydraulic hose	TTF	Weibull 2	6,3274	1598,9748	–	–	–
			TTR	Weibull 3	1,3328	2,0103	2,6500	–	–
2	Hydraulic Pump	Regulator seal kit damaged	TTF	Weibull 2	8,6767	4824,0482	–	–	–
			TTR	Log normal	6,6870	4,7277	0,0700	1,4979	0,1330
3	Fuse box	The fuse has blown	TTF	Weibull 2	10,0346	2154,8462	–	–	–
			TTR	Weibull 3	2,3418	2,3746	1,8175	–	–
4	Track roller	Track roller damaged	TTF	Weibull 2	10,9212	5459,8703	–	–	–
			TTR	Weibull 3	3,2963	3,9422	2,4725		
5	Carrier roller	Carrier roller damaged	TTF	Normal	4,8509	4827,1304	–	4457,000 1	975,1010
			TTR	Weibull 3	1,5142	1,8999	4,1600	–	–
6	Track shoe	Shoe bolt loose	TTF	Weibull 2	4,9787	811,3584	–	–	–
			TTR	Weibull 3	1,0934	1,7709	3,4050	–	–
7	Oil Filter	Oil Filter damaged	TTF	Weibull 2	5,9247	1434,9773	–	–	–
			TTR	Weibull 3	3,6301	4,9067	0,7075	–	–
8	Diesel Filter	Diesel Filter damaged	TTF	Weibull 2	6,1166	1968,8333	–	–	–
			TTR	Weibull 3	1,8572	2,2558	2,9325	–	–
9	Air Filter	Air Filter damaged	TTF	Weibull 2	6,3803	1643,0448	–	–	–
			TTR	Weibull 2	4,1063	5,8287	–	–	–
10	Boom cylinder	Seal boom damaged	TTF	Weibull 2	2,9057	7980,8348	–	–	–
			TTR	Weibull 3	1,3628	2,3659	2,1925	–	–
11	Armcylinder	The cylinder rod is worn/dama ged	TTF	Weibull 2	14,9323	2549,0920	–	–	–
				Weibull 2	3,6322	9,0866	–	–	–
12	Front idler	Front idler damaged	TTF	Normal	9,2684	2738,9167	–	2587,625 0	411,0793
			TTR	Normal	2,4817	9,5960	–	8,4000	3,4731

TABLE 3.
MTTF AND MTTR CALCULATION RESULTS

No	Component	*Failure mode*	Distribution	*MTTF* (hour)	*MTTR* (hour)
1	Hydraulic Hose	Leaking hydraulic hose	*Weibull 2*	1486,7268	
			Weibull 3		4,4977
2	*Hydraulic Pump*	*Regulator seal kit damaged*	*Weibull 2*	4551,9719	
			Log normal		4,5120
3	*Fuse box*	The fuse has blown	*Weibull 2*	2050,1207	
			Weibull 3		3,9214
4	*Track roller*	*Track roller* damaged	*Weibull 2*	5216,9061	
			Weibull 3		6,0106
5	*Carrier roller*	*Carrier roller* damaged	Normal	4457,0001	
			Weibull 3		5,8731
6	*Track shoe*	Shoe bolt loose	*Weibull 2*	744,9893	
			Weibull 3		5,1143
7	Oil Filter	Oil Filter damaged	*Weibull 2*	1330,0681	
			Weibull 3		5,1270
8	Diesel Filter	Diesel Filter damaged	*Weibull 2*	1830,6212	
			Weibull 3		4,9361
9	Air Filter	Air Filter damaged	*Weibull 2*	1527,7031	
			Weibull 2		5,2954
10	*Boom cylinder*	*Seal boom* damaged	*Weibull 2*	7120,5008	
			Weibull 3		4,3566
11	*Armcylinder*	The cylinder rod is worn/damaged	*Weibull 2*	2457,8345	
			Weibull 2		8,1843
12	*Front idler*	*Front idler* damaged	Normal	2587,6250	
			Normal		8,4000

TTR data that has a log-normal distribution is a hydraulic pump. Meanwhile, TTR data with a Normal distribution is a front idler. The Log normal distribution type produces the parameters Beta (β), Gamma (γ), Eta (η), Mean (μ), and Std (σ)The next step is to calculate the Mean Time To Failure (MTTF) and Mean Time To Repair (MTTR) values for each component that has damage data. The following is an example of MTTF and MTTR calculations for a hydraulic pump component with a failure mode, a damaged regulator seal kit for a 2-parameter Weibull distribution type and lognormal distribution, as well as a carrier roller component with a 3-parameter Weibull distribution type and a normal distribution.

The following are the results of calculating MTTF and MTTR values for excavator components which can be seen in table 3.

D. Maintenance Cost Calculation

At this stage, maintenance intervals are calculated for excavator components. This calculation requires information regarding costs related to maintenance such as maintenance costs (CM) and repair costs (CR) for each component.

a. Calculation of Maintenance Costs / Cost of Maintenance (CM)

In this step of calculating maintenance costs (CM), data is needed regarding the costs of wages or salaries of workers who carry out preventive maintenance actions, as well as the costs of materials or materials that will be used for maintenance purposes. Excavator heavy equipment maintenance activities are carried out by 2 mechanical officers. The total cost of salary per hour is IDR 75,000. Maintenance at construction companies is carried out by a third party with a salary of IDR 300,000 per day. Preventive maintenance activities carried out on excavators include checking the condition of the machine based on a checklist form and lubrication of several components.

The total results of the calculation of maintenance cost allocation (CM), which is the total cost per hour, is IDR 80,536.1111.

This result is a calculation of the mechanical cost of components and maintenance materials required per hour. Materials needed for maintenance are obtained from information from related parties, where the monthly consumption per material is multiplied by the unit price. The total produced is made into material cost units per hour.

b. Calculation of Repair Costs / Cost of Repair (CR)

Repair costs or Cost of Repair (CR) arise due to components of the excavator being damaged, requiring repair/replacement of components or sub-components. Elements of repair costs consist of man-hours costs (CW), operational consequences costs due to the machine not operating during the damage period (CO), as well as component recovery or replacement costs (CF).

1. Cost of Man Hours (CW)

This cost is defined as the cost of labor that carries out repair actions when damage occurs to excavator components. The repair workforce is 3 people, consisting of one chief mechanic and two mechanical officers. These mechanical workers are workers from third parties who are called upon when damage occurs to the excavator. In 1 day the salary for mechanical officers is IDR 300,000 and the chief mechanic is IDR 500,000. Mechanic working hours every day are 8 hours. The total costs incurred by construction companies for repair activities (CW) are IDR 137,500 per hour, assuming that all workers are always available to carry out maintenance or repair activities. The workforce consists of 1 chief mechanic and 2 mechanics.

2. Operational Consequence Costs (CO)

Operational consequence costs are defined as costs that arise due to downtime on the excavator, which causes the company to lose production (loss of production) and not operate. The amount of CO costs can be calculated by calculating project delay costs as follows:

CO = 1/1000 x Contract value
= 1/1000 x IDR 146,161,697,000
= IDR 146,161,697 per day
= Rp. 12,180,141 per hour

3. Cost of component repairs per maintenance cycle (CR)

These costs are defined as costs that arise due to a malfunction of an excavator component that requires replacement or replacement reserves. The price per component for component replacement costs is obtained from the price of components sold on the market according to the excavator brand.

The amount of repair costs (CF) incurred by the company can be calculated using the following method. The following is an example of calculating repair costs (CR) for hydraulic hose components.

Is known:
CF = IDR 650,000
CW = Rp. 137,500
CO = IDR 12,180,141
MTTR = 4.4977 hours

So that CR = CF + ((CW + CO) x MTRR) = 650,000 + ((137,500 + 12,180,141) x 4.4977) = Rp. 56,051,056/ hour

E. Maintenance Interval Calculation

After calculating the maintenance costs (CM) and repair costs (CR) on the excavator, the next step is to calculate the optimal maintenance interval (TM) for components that receive the scheduled restoration task and scheduled discard task maintenance policies. The maintenance interval calculation for each component depends on the distribution parameter values that have been obtained previously, along with costs related to maintenance such as Cost of Maintenance (CM) and Cost of Repair (CR) for each component. The following is an example of a TM calculation for a hydraulic hose.

The distribution type is TTF – Weibull 2
β = 6.3274
η = 1598.9748
CM = Rp. 80536.1111/ Hour
CR = Rp. 56,051,056/ Hour

So, the calculation of the optimal maintenance interval (TM) is as follows.

TM = η [1/(β-1) X CM/(CR-CM)] ^(1/β), Weibull distribution 2
= 1598.9748 [1/(6.3274-1)
= 1598.9748X 0.2729
= 436.3836 hours

For components with scheduled discard task maintenance intervals that have a normal distribution type, a formula with the equation TM = ½ MTTF is used [5]. The following is an example of calculations for a carrier roller with normal distribution.

Distribution type is TTF – Normal
β = 4.8509
η = 4827.1304
μ = 4457.0001
σ = 975.1010
MTTF = 4457.0001

So, the calculation of the optimal maintenance interval (TM) is as follows:

TM = ½ MTTF
= ½ 4457.0001
= 2228.5 hours

The rule for determining the scheduled on-condition task maintenance time interval is half of the P-F interval. The P-F interval is defined as the interval between the occurrence of potential failure and the condition of functional equipment failure [4]. It is known that the track shoe maintenance interval is 360 hours. The way to determine the initial interval of the scheduled on-condition task component is half of the P-F interval. The P-F interval value is obtained from expert judgment in the field.

The components analyzed using the RCM II Decision Worksheet are critical components that have experienced failure. Components that are supported by the availability of data on failures that have occurred, these components are analyzed further through the RCM II Decision Worksheet filling stage to identify the appropriate type of maintenance activity/proposed task [5].

The columns in the RCM II Decision Worksheet are answered using the help of the RCM II Decision Diagram. The total excavator components analyzed by the RCM II Decision Worksheet were 12 components.

Based on the calculation results from the failure data for each component, various TTF and TTR values were obtained so that the resulting distribution parameters also had different values. Data processing produces 3 types of maintenance policies, namely scheduled restoration task, scheduled discard task, and scheduled on condition task. The component that has a scheduled restoration task maintenance policy with the highest TM value is the arm cylinder with failure mode, the cylinder rod is worn or damaged and has a TM value of 1322.8292 hours. The component that has a scheduled discard task maintenance policy with the highest TM value is the track roller with failure mode, the track roller is damaged and the TM value is 2367.0005 hours. Components that have a scheduled on-condition task maintenance policy are track shoes with a loose shoe bolt failure mode and have a TM value of 360 hours.

TABLE 4.
RCM II DECISION WORKSHEET EXCAVATOR

RCM II DECISION WORKSHEET		***System: Excavator***													***Date:* July 2023**	***Sheet No.:***	***01***
		***Sub-System:* Hydraulic**														***Of:***	***05***
No	***Equipment***	***Information Reference***			***Consequence Evaluation***				***H1 S1 E1 O1***	***H2 S2 E2 O2***	***H3 S3 E3 O3***	***Default Action***			***Proposed Task***	***Initial Interval* (hour)**	***Can be done by***
		F	***FF***	***FM***	***H***	***S***	***E***	***O***				***H4***	***H5***	***S4***			
1	Hydraulic Hose	*1*	*A*	*1*	*Y*	*N*	*Y*	-	*N*	*Y*	-	-	-	-	***Scheduled restoration task*** *-Overhaul the hydraulic hoses* *- Replace damaged hydraulic hoses*	*436,3836*	Mechanic
2	*Hydraulic pump*	*1*	*A*	*2*	*Y*	*N*	*N*	*Y*	*N*	*N*	*Y*	-	-	-	***Scheduled discard task*** *-Replace the regulator seal kit*	*1793,1120*	Mechanic
3	*Hydraulic Pump*	*1*	*A*	*1*	*Y*	*N*	*N*	*Y*	*N*	*N*	*Y*	-	-	-	***Scheduled discard task*** *-Replace the oil filter*	*355,7168*	Mechanic
4	*Boom cylinder*	*1*	*A*	*1*	*Y*	*N*	*Y*	-	*N*	*N*	*Y*	-	-	-	***Scheduled discard task*** -Replace the boom seal	*680,1725*	Mechanic
5	*Fuse box*	*1*	*A*	*2*	*Y*	*N*	*N*	*Y*	N	*Y*	-	-	-	-	***Scheduled restoration task*** -Cleaning and lubricating the arm cylinder	*1322,8292*	Mechanic
6	Filter solar	*1*	*A*	*1*	*Y*	*N*	*N*	*Y*	*N*	*N*	*Y*	-	-	-	***Scheduled discard task*** -Replace the diesel filter	*509,3161*	Mechanic
7	*Track roller*	*1*	*A*	*1*	*Y*	*N*	*N*	*Y*	*N*	*Y*	-	-	-	-	***Scheduled restoration task*** -Clean the air filter using a compressor	*441,2358*	Mechanic

The RCM method is used in preparing appropriate maintenance strategies according to the criticality level of components based on the data that has been collected [14]. Maintenance is generally categorized into 2 ways, namely planned maintenance and unplanned maintenance. Planned maintenance is divided into two main activities, namely preventive maintenance and corrective maintenance. Preventive maintenance is a periodic inspection activity including lubrication, calibration and testing to identify potential conditions that could cause production disruptions or reduced machine function, which is then followed by maintenance to eliminate or control these conditions, and return the machine to its original condition. beginning. Corrective maintenance is equipment maintenance activities that are carried out repeatedly to repair a part that has stopped functioning so that it meets acceptable conditions including planned repairs and overhauls. Unplanned maintenance is maintenance carried out when the equipment used is accidentally damaged and repairs are carried out.

Based on the research results of Dio et al, the Excavator Maintenance Strategy Using the RCM Method is able to provide savings from the proposed strategy of $ 290.47 or Rp. 4,088,024.21 per hour [14].

Meanwhile, in Iva et al's research on the Implementation of RCM II by considering maintenance risk costs, component replacement costs, failure costs, and labor costs, it is known that the results of calculating maintenance intervals can avoid failure before the time the damage occurs, and reduce the value of failure experienced by component is far below its MTTF value [15].

IV. CONCLUSION

The study's findings indicate that 43 different types of failure, or failure modes, have the potential to result in functional failure in the excavator. These failure modes were identified using the FMEA (Failure Modes and Effects Analysis) technique of failure detection. The track shoe component with the loose shoe bolt failure mode has the highest RPN component value, 60, according to the results of the risk assessment using RPN (Risk Priority Number). When a blade component experiences a failure mode—that is, when the blade is cracked or broken—the lowest RPN value is 3. Three different types of activities and distinct outcomes are found in the maintenance activities based on the RCM II Decission Worksheet for each. Specifically, there is one scheduled on-condition task for track shoe components with a time value of 360 hours, three scheduled restoration task for components fuse box with a time value of 914.9099 hours, an air filter with a time value of 441.2358 hours, and an arm cylinder with a time value of 1322.8292 hours. Additionally, there is eight scheduled discard task, for hydraulic hose components with a time value of 436.3836 hours, a hydraulic pump with a time value of 1793.1120 hours, a track roller with a time value of 2367.0005 hours, a carrier roller with a time value of 2228.5 hours, an oil filter with a time value of 355.7168, a diesel filter with a time value of 509.3161 hours, a boom cylinder with a time value of 680.1725 hours, and a front idler with a time value of 1293.8125 hours.

ACKNOWLEDGEMENTS

Thank you to the Surabaya State Shipping Polytechnic for the support of its facilities and the research team who worked together to complete this research.

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