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Improving Analysis of Risk-Based Maintenance Management Strategies Through Reliability Centered Maintenance. Case Study : Coal Crushing Plant. Central Kalimantan. Indonesia

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Abstract. PT XYZ as a company operating in the coal mining sector has 7 production lines on the in-loading system in its coal crushing plant. In-loading system production line no. 7 is the system that has the lowest mechanical availability; therefore, it is necessary to search for a systematic method to obtain an appropriate maintenance mode and not only consider operational aspects but also pay attention to occupational health & safety aspects. RCM is a qualitative analysis (which can be developed into quantitative analysis) which formulates maintenance task selection based on safety, environmental and operational considerations. From the results of the FMEA research, it was found that there were 28 failure modes with 6 components of which had an unacceptable risk level and a critical level of "very critical" so that LTA analysis was carried out on these 6 components and obtained maintenance tasks for each component, namely scheduled on condition tasks (HPU pump, Drag Chain, Hydraulic Pipe) and redesign (Flight bar, Flap Plate).

Keywords: Risk Analysis, Reliability, FMEA, RCM Feeder System

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1. Background of the problem

Especially for companies in the coal mining sector, increasing productivity in the production system is an absolute must. If a machine experiences a breakdown, the company's productivity will be disrupted because downtime has the effect of decreasing the amount of output, increasing operational costs, and affecting customer service [1]. One indicator of increasing productivity is the level of reliability of the company's production machines. "Reliability is the possibility that a system will carry out its function/performance satisfactorily; in certain work environments and operating conditions" [2]. In measuring how good the reliability of a production machine is, an effective and efficient maintenance process is needed for the company.

PT. XYZ is a coal company that has a business license to carry out mining activities under the Coal Mining Concession Contract Agreement with the Indonesian government in the South Kalimantan and Central Kalimantan regions. Specifically, in Central Kalimantan, PT XYZ has placed a coal crushing plant which mainly functions to crush the coal into smaller pieces according to consumer demand before the coal is sent out using barges. Delays in coal production operations due to frequent downtime and long repair times due to repairs during downtime are obstacles to achieving targets that need to be anticipated and maintenance program policies taken by the maintenance department also need to be carried out with careful consideration so that maintenance results are optimal.

In this research, it focuses on production equipment in the crushing plant area. It is known that PT XYZ divides the production line into two lines, namely the inloading (upstream) and outloading (downstream) lines. From the results of processing historical data on production equipment maintenance for the 2022 period, the inloading line is the line that has a lower Mechanical Availability value than the outloading line, namely 97.81%, while the Mechanical Availability value for outloading is 99.22%, where the target of Mechanical Availability is 96%. PT XYZ itself has 7 inloading lines in which there is a hopper system, feeder system, screening system, crushing system and conveyor system. When processing production equipment maintenance history data for the 2022 period, the Mechanical Availability value of the 7 inloading lines is obtained where there is 1 production line that has Mechanical The lowest availability is inloading route number 7 at 95.36% of the target that must be achieved at 96% with the MTBF (mean time between failure) value on inloading line number 7 having an average of 272.43 hours with an MTBF target of 950 hours.

Preventive maintenance, corrective maintenance, predictive maintenance, breakdown maintenance and improvement maintenance (design-out maintenance) activities have been carried out by PT XYZ in order to maintain the function of each system or subsystem continues to run normally and in carrying out maintenance activities both in terms of intervals and maintenance modes, there are conditions based and the majority are based on considerations from the manual book for each production equipment and trends in the usage life of production equipment. From existing maintenance activities, there needs to be a systematic, risk-based method to maximize decision making regarding maintenance mode management. One way is through RCM (Reliability Centered Maintenance). RCM is a systematic approach based on risk to create an accurate, focused, and optimal maintenance mode [3] and RCM is a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context. RCM is used to develop a maintenance plan with a certain level of operation, with a certain level of risk, which is efficient and price effective [4]. RCM is continuous, which means that this process can (even at best) be repeated to get a higher reliability value, which makes decisions related to determining maintenance intervals and modes more scientific, effective, and efficient.

Several previous studies regarding the RCM-based maintenance process, one of which was carried out by Ma, et al [6] which was applied to heavy equipment vehicles in coal mining in China to determine the maintenance period and maintenance mode from three basic maintenance modes, namely corrective maintenance, periodic maintenance, and status maintenance. using the RCM approach which provides an increase in economic benefits, then other RCM-based research conducted by Wu and Wang [7] which is applied to the maintenance management system of electromechanical equipment in coal mining companies and provides the impact of saving maintenance costs and improving operational quality of equipment, and then from other research on RCM, it is concluded that many organizations are exploring alternative maintenance methods that seek to improve the reliability and availability of the plant and equipment and the RCM is the most successful method for developing failure management policies with the aim of sustaining the performance of physical assets, reduced preventive maintenance costs, reduced corrective maintenance costs, reduced labor costs, reduced outage costs, reduced spare parts costs, increased plant availability, increased plant reliability, reduced maintenance frequency and an increase in production . [8].

Based on previous research conducted regarding RCM, it is hoped that analysis of risk-based maintenance management strategies through RCM which is carried out at the PT XYZ crushing plant, especially on the no.7 inloading production line system, can increase the availability and reliability of the system.

2. Research Methods

This research was conducted from November 2022 to May 2023 at the PT XYZ crushing plant which is operational in Central Kalimantan. Research starts from collecting data such as machine/component data, machine/component downtime (damage) data and machine/component uptime (repair) data which conducted from November 2022 to Januari 2023. After that, steps are taken to prepare RCM-based improvement activities which were carried out from February 2023 to May 2023. There are 7 steps in making RCM [9], namely : (1) Defining system boundaries, (2) Explanation of system and function block diagrams, (3) Explanation of system functions and functional failures, (4) Preparation of FMEA and analysis of critical components, (5) Logic Tree Analysis, which is a continuation of FMEA to add consideration in selecting maintenance activities, (7) analysis of selecting maintenance activities based on the RCM flowchart decision diagram [9] In addition, Pareto analysis and fault trees are also used in FMEA analysis. Pareto a theory maintaining that 80 percent of the output from a given situation or system is determined by 20 percent of the input while Fault Tree Analysis (FTA) is a technique used to identify risks that contribute to failure [15]. Pareto is useful for determining the priority of systems, sub-systems or critical components that will be analyzed further and FTA is used to determine existing failure modes and causes.

3. Results and Discussion

3.1 System definition and Functional Block Diagram

Inloading production line system no.7 has 9 sub-systems, namely feeder sub-system, S17 conveyor, S18 conveyor, S19 conveyor, diverter, primary crusher, secondary crusher, tertiary crusher, screener. Through the use of the Pareto diagram, it is obtained that the feeder sub-system has a high percentage as seen from the frequency and duration of damage using component damage data in the unplanned maintenance schedule category or in this case reactive maintenance/ breakdown maintenance for the period January 2019 – December 2022 as seen in the Pareto diagram (80:20) which shows that the feeder sub-system is a priority for RCM analysis in this research

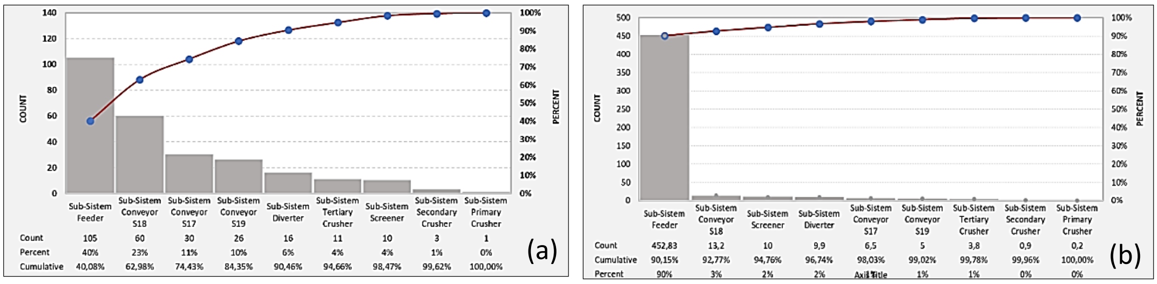


Figure 1. (a) Frequency & (b) Duration of Damage Production System of Inloading line no.7

Through field observations and data observations, information and work processes were obtained which were outlined in function block diagrams [10] to visualize the flow of function processes from the feeder sub-system into a simple diagram.

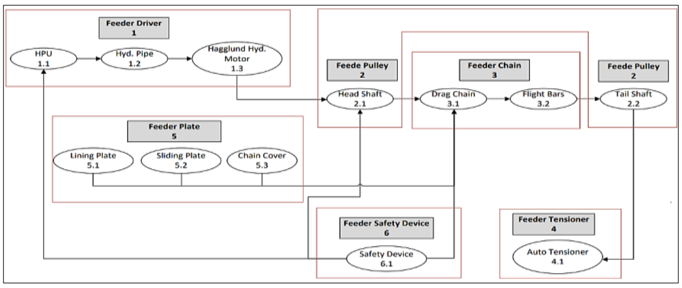


Figure 3. Functional Block Diagram of Feeder Sub-System FD0055-007

3.2 FMEA Results

FMEA is one of the most fundamental methods for evaluating the level of risk as a prelude to risk reduction [11]. In this research, FMEA is prepared based on the description of the feeder sub-system with the identity FD0055-007 which is divided into several components to arrive at an acceptable one. The main components of the feeder sub-system are:

1. Feeder drivers which consists of a hydraulic power unit, hydraulic pipe, Hagglund hydraulic motor
2. Feeder pulley which consists of a head shaft assembly and a tail shaft assembly
3. Feeder chains which consists of a 5.5” drag chain, flight-bar
4. Feeder tensioner which consists of an auto-tensioner
5. Feeder plates which consists of lining plate, sliding plate, chain cover
6. Feeder safety device consisting of a safety device (“slack” sensor, electric motor and pump sensor, “under-speed” sensor)

Then, based on the component details from FD0055-007, functional failure, failure mode and causes of failure are searched using the fault tree analysis method.

Table 1. FMEA Analysis (Component, Function, Function Failure, Failure Mode)

C	Component	F	Function	FF	Function Failure	FM	Failure Mode
1	Hydraulic Power Unit	A	Increase oil pressure to move the Hagglund (hydraulic drive) within the specified vibration pressure and temperature limits	1	Failed to increase oil pressure to move the Hagglund (hydraulic drive) within the specified vibration pressure and temperature limits	1	The hydraulic pump experiences abnormal conditions (oil leaks, extreme increases in pressure, temperature and vibration) so that the pump cannot operate normally
						2	Electric motor damage
						3	Rubber coupling damage
						4	Clogging filter
						5	Fan drive motor failure
						6	The fan does not rotate optimally
						7	There is a leak in the tank
2	Pipe/ Hose	A	Connects and delivers high pressure oil throughout the hydraulic system without leaks	1	Failed to connect and deliver high pressure oil throughout the hydraulic system without leaks	1	Oil leaks in pipes/hoses
3	Hagglund Hydraulic Motor	A	Provides rotational force/torque on the head shaft within the specified vibration pressure and temperature limits	1	Failed to provide rotational force/torque on the head shaft	1	The hydraulic motor experiences abnormal conditions (oil leaks, extreme increases in pressure, temperature and vibration) so that the pump cannot operate normally
4	Head Shaft Assembly	A	Continuing the torque produced by the hydraulic motor (hagglund) to rotate the sprocket and pull the drag chain	1	Failed to transmit the torque produced by the hydraulic motor (hagglund) to rotate the sprocket	1	Broken Shaft
						2	Worn sprockets
						3	Damage to bearing components
5	Tail Shaft Assembly	A	Connect the idler and pull up the drag chain	1	Failed to connect the idler and pull up the drag chain	1	Broken Shaft
						2	Flap Plate Dislodged
						3	Worn idler
						4	Damage to bearing components
6	Drag Chain 5.5	A	Moving the coal load to the crushing process	1	Failed to move the coal load to the crushing process	1	Dragchain disconnected
						2	Dragchain does not move
7	Flightbar	A	Pushing the load into the crusher area	2	Failed to push the coal load to the crusher area optimally	1	Flightbar Detached

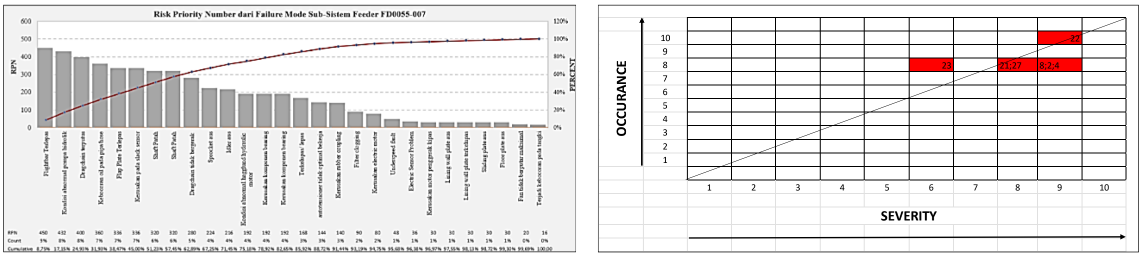
8	Auto Tensioner	A	Drag chain tension adjuster	1	Failed to provide drag chain tension adjustment	1	autotensioner is not working optimally
9	Lining Wall Plates	A	Holds coal in the feeder	1	Failed to hold coal and flightbar located on the feeder	1	Lining wall plate worn
						2	The lining wall plate is peeling off
10	Sliding Plates	B	drag chain base	1	Failed to provide support to the drag chain	1	The sliding plate is worn
11	Floor Plates	C	The coal platform goes to the crusher	1	Failed to provide support for the coal going to the crusher	1	Floor plate worn
12	Chain Cover	D	Protects the chain from direct coal impact	1	Failed to protect the chain from direct coal impact	1	Peeling/loose
13	Safety devices	A	Protect feeder components from anomalous conditions when the feeder is operational	1	Protect feeder components from anomalous conditions when the feeder is operational	1	Electric sensor problem
						2	Damage to the slack sensor
						3	Underspeed fault

After that, a risk priority number assessment is carried out by multiplying severity, occurrence, and detection for each failure mode.

Table 2. FMEA Analysis (RPN, Risk Level, Critical Level)

No. C	**No. F**	**No. FF**	**No. FM**	**S**	**O**	**D**	**RPN**	**Risk Level**	**Critical Level**
1	A	1	1	9	8	6	432	Unacceptable	Very Critical
			2	8	2	5	80	Tolerable	High
			3	6	4	3	72	Tolerable	High
			4	5	4	2	40	Tolerable	Medium
			5	5	2	3	30	Acceptable	Minor
			6	5	2	2	20	Acceptable	Minor
			7	8	2	1	16	Acceptable	Minor
2	A	1	1	9	8	5	360	Unacceptable	Very Critical
3	A	1	1	8	2	2	32	Tolerable	Medium
4	A	1	1	10	2	7	140	Tolerable	High
			2	7	2	3	42	Tolerable	Medium
			3	7	2	3	42	Tolerable	Medium
5	A	1	1	10	1	7	70	Tolerable	High
			2	8	6	7	336	Unacceptable	Very Critical
			3	9	4	6	216	Unacceptable	Very High
			4	7	2	4	56	Tolerable	Medium
6	A	1	1	9	8	5	360	Unacceptable	Very Critical
			2	7	8	5	280	Unacceptable	Critical
7	A	2	1	9	10	5	450	Unacceptable	Very Critical
8	A	1	1	5	6	3	90	Tolerable	High
9	A	1	1	5	6	1	30	Acceptable	Minor
			2	5	6	1	30	Acceptable	Minor
10	B	1	1	5	6	1	30	Acceptable	Minor
11	C	1	1	5	6	1	30	Acceptable	Minor
12	D	1	1	6	6	2	72	Tolerable	High
13	A	1	1	4	4	3	36	Tolerable	Medium
			2	6	8	7	336	Unacceptable	Very Critical
			3	4	4	3	48	Tolerable	Medium

After processing the RPN values for the 28 failure modes found, the risk level and criticality level of the components are determined based on the RPN values obtained from multiplying the severity, occurrence and detection factors with the predetermined assessment criteria. After that, a more in-depth criticality level analysis is carried out through Pareto creation to determine the components that play a role in the decline in performance of FD0055-007 and a criticality level matrix that will visualize the values of severity and occurrence so that each failure mode that has the same RPN value can be sorted based on the impact it will have. felt when the failure occurs.



(a) (b)

Figure 4. (a) Pareto risk priority number of feeder sub-system failure mode FD0055-007, (b) Critical matrix

From the results of mapping the criticality level on the critical matrix, the priority of failure modes in the FD0055-007 feeder sub-system is sequentially, namely fligtbarloose (22) on the flightbar component, the hydraulic pump experiences an abnormal condition (oil leak, extreme increase in pressure, temperature and vibration) so that the pump cannot operate normally (2) on the hydraulic power unit component, oil leaks on the pipe/hose (4) on the hydraulic power unit component, the drag chain broke (21) on the 5.5” chain component, the flap plate came off (27) on the tail shaft assembly component, and damage to the slack sensor (23) on the drag chain component – chain slack sensor.

3.3 Logic Tree Analysis and Maintenance Task Selection

LTA is a continuation of FMEA analysis and has the aim of giving priority to each damage mode and reviewing and functioning failures so that the status of the damage modes is not the same [12]. the results will be used as input in the logic tree analysis analysis to add consideration to the selection of maintenance tasks in RCM [13]. The following is a flowchart for the analysis of logic tree analysis and maintenance selection tasks [4].

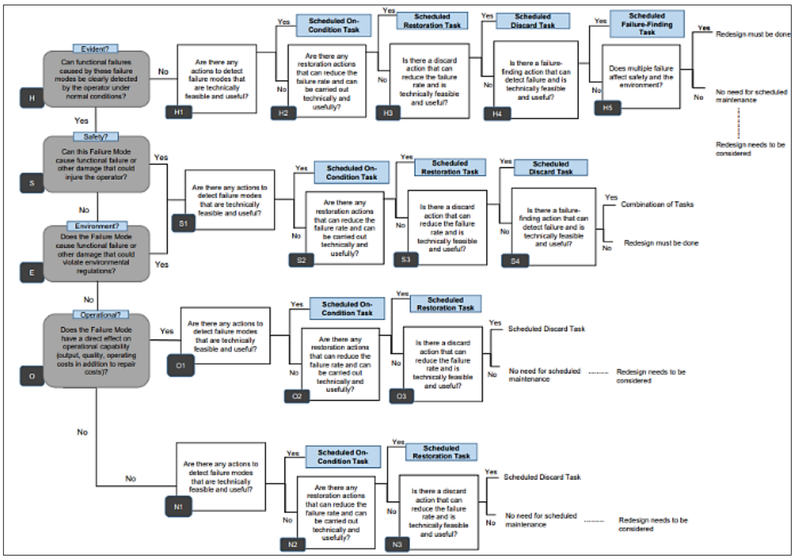


Figure 6. Flowchart of RCM decision diagram

From the results of the logic tree analysis and maintenance task analysis, recommendations for types of maintenance are produced which are outlined in the RCM II worksheet. RCM II decision worksheet is the next phase after the FMEA, or the RCM II information worksheet is done. Decision worksheet is a summary of every question listed in the RCM II decision diagram [14]. The RCM II decision worksheet is as follows:

Tabel 3: RCM II Decision Worksheet

Information Reference				**Consequences Evaluation**				**H1 S1 O1 N1**	**H2 S2 O2 N2**	**H3 S3 O3 N3**	**Default Action**			**Proposed Maintenance Task**
C	**F**	**FF**	**FM**	**H**	**S**	**E**	**O**				**H4**	**H5**	**S4**	
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	
7	A	2	1	Y	N	N	Y	N	N	N				*Redesign* : Dimensions and geometry of the flight bar need to be considered for changes
1	A	1	1	Y	N	N	Y	N	N	Y				*Scheduled on-condition task* : Checking & replacing the input bearing & seal, replacing pump when it fails
6	A	1	1	N	N	N	Y	N	N	Y				*Scheduled on-condition tasks*: Checking link plate thickness, elongation and replacing the drag chain when it fails
2	A	1	1	N	N	N	Y	Y						*Scheduled on-condition tasks*: Replacement of pipe/hose when the thickness of the pipe is no longer able to withstand the operational pressure of the HPU
5	A	1	2	Y	N	N	Y	N	N	N				*Redesign:* Dimensions and geometry of the flap plate need to be considered for changes
13	A	1	2	Y	N	N	Y	Y						*Scheduled on-condition task:* Checking the accuracy of the sensor regarding the installed mechanical trigger, checking the overall chain slack sensor

From the results of the risk evaluation outlined in the RCM decision worksheet, maintenance modes for each critical component were obtained to increase the reliability of the production line for inloading system no. 7 is by re-engineering or redesigning the flight-bar (chain 5.5”) and flap plate (tail shaft assembly) components and carrying out repair/replacement activities when abnormal conditions are found on the equipment or scheduled on-condition tasks for the components hydraulic pump (HPU), drag chain (chain 5.5”), hydraulic pipe (HPU), slack sensor (safety device).

4. Conclusion

In this research, through the Reliability Centered Maintenance process, several conclusions were obtained, Through Pareto diagram analysis, the feeder sub-system FD0055-007 is a contributor to the low availability value of the production line for inloading system no.7. The FMEA process shows several components that are categorized as having an "unacceptable" risk level. Then a critical level analysis is carried out to obtain 6 components which are sorted based on the negative impact they have and are categorized as "very critical". Components with a "very critical" status are then subjected to a logic tree analysis which is connected to the maintenance mode through a flowchart decision diagram based on safety, environmental, operational, and non-operational aspects. RCM in qualitative analysis can be used as a systematic method that formulates maintenance mangement strategies based on safety, environmental, operational, and non-operational factors. RCM analysis can also be developed with quantitative reliability analysis using statistical distribustion (weibull, lognormal, normal exponential, etc) to obtain maintenance activity intervals as well as considering maintenance costs so that maintenance management strategies become more comprehensive.

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