Maintenance Management Analysis and Risk Assessment Using Failure Mode & Effect Analysis (FMEA) Method on Heavy Equipment Unit at PT XYZ

Salmaa Nabiilah Alwiyansyah, Fransisca Dini Ariyanti
Industrial Engineering Department, Faculty of Engineering
Bina Nusantara University
Jakarta, 11480, Indonesia
salmaa.alwiyansyah@binus.ac.id, dini.ariyanti@binus.ac.id

Abstract

PT XYZ is a leading distributor of heavy equipment in Indonesia. During Covid-19 pandemic situation some heavy equipment has stopped operating, but inspection are still required. With excellent inspection and follow-up performance the potential for failure can be reduced so that the Physical Availability (PA), Mean Time Between Failure (MTBF) and scheduled breakdown hours performance of the unit are better. PT XYZ has three basic principles of maintenance strategy namely preventive management, predictive management and corrective maintenance. Based on the results, the percentage of inspection follow up with the percentage of PA shows a moderate positive correlation, and the correlation within the percentage of inspection follow up and the performance of MTBF is a weak correlation. Scheduled breakdown hours and the percentage of PA level shows no correlation between those two variables. The correlation between scheduled breakdown hours and MTBF performance is a weak negative correlation. The top three of Risk Priority Number (RPN) values are owned by the electrical system (500), brake system (400), and engine components (256). The Risk Severity Number (RSV) values for the top priority components are 50, 50, and 64 respectively.

Keywords
Inspection Follow Up, Physical Availability, MTBF, Scheduled Breakdown Hours and Risk Priority Number.

1. Introduction

In the world of mining and any construction work, heavy equipment is used as a production tool. Every heavy equipment must always be in RFU (Ready for Use) status. In maintaining the Availability and performance of heavy equipment we must implement a maintenance strategy such as Preventive maintenance, Predictive maintenance and Corrective maintenance. Preventive and Predictive maintenance are applied in order to minimize the occurrence of unscheduled breakdown, and Corrective maintenance or reactive maintenance is applied when unscheduled breakdown occurs to a unit. According (Rajaprasad, 2018), Reliability and maintainability of the paper machine has been evaluated at various times which are useful for establishing the preventive maintenance scheduled for improving availability of the paper machine.

Unscheduled breakdown maintenance is a maintenance caused by an unexpected failure. The occurrence of unscheduled breakdown usually caused by sudden failure of the unit components. Therefore, the author intend to find the correlation between inspection follow up variable with Physical Availability and MTBF variables, and scheduled breakdown hours variable with Physical Availability and MTBF variables that affect the result of maintenance (Aribowo & Kurniati, 2019). It is crucial to conducted Failure Mode & Effects Analysis method to assess the potential failure of unit component or parts so that a mitigation action can be taken to avoid or prevent any unscheduled breakdown.

FMEA is an effective and accepted tool in the application to prevent or reduce the breakdown issues of any machines. It contains the potential failure mode, causes of failure mode, effects of failure mode and represents RPN form which can be calculated by the product of Severity (S), Occurrence (O), and Detection (D) (Ariyanti & Andika, 2016). Once the risk assessment is done, the next step is to find the mitigation action to cope the causes of failure (Wannawiset & Tangjitsitcharoen, 2019).

1.1 Objectives

The focus of this study is to determine the actions that must be taken to reduce the occurrence of unscheduled breakdown by finding out the correlation between inspection follow up, Physical Availability, Mean Time Between Failure, and scheduled breakdown hours variables and assessing the potential of components failure to prevent unscheduled breakdown. In order to fulfil the focus of study following objectives were defined:

1. To measure the correlation between percentage level of inspection follow up with the percentage level of PA, and the correlation between percentage level of inspection follow up with the performance of MTBF.
2. To measure the correlation between scheduled breakdown hours with the percentage level of PA, and the correlation between scheduled breakdown hours with the performance of MTBF.
3. To assessing the risk of component failure and find the mitigation actions.

2. Literature Review

There are two maintenance breakdowns for a machine, namely scheduled maintenance and unscheduled maintenance. Unscheduled breakdown maintenance is a maintenance for unexpected failure (Rumane, 2017). Unscheduled breakdown basically occurs because a unit is operated continuously until the failure occurs causing the unit to become inoperable without routine maintenance and repair or replacement of spare parts. Unscheduled breakdown maintenance included into corrective maintenance because the actions taken are caused by sudden unit failure (Niu, 2017). Mean Time Between Failure is a statistical value that shows an average time between the previous failure until the next failure occurs (Bhargava, 2020). Mean Time to Repair is a measurement of the average time when the failure occurs until the repair is done (Dulaney & Easttom, 2018). Physical Availability is a value that states the ready for use number of units to do a production at certain time intervals (Elattar, 2020).

Correlation is a measurement used to examine the strength and direction of the relationship between two or more variables, either continuous or categorical data. The correlation between two variables may be considered very strong, strong, moderate, weak, or very weak (Abu-Bader, 2021). A scatterplot is a representation graph of two variables for observing relationships between pairs of variables, wherein the changes in one variable is followed through in the changes in another variable (Samanta, 2019). Scatterplot is a visualization technique that is used extensively in data analysis and is a powerful way of conveying information about the relationship between two variables (Martinez, et al. 2017, & Solka, 2017). In the scatterplot diagram each variable is represented by an axis, independent variable on the x axis and dependent variable on the y axis (Warne, 2020).

Failure Mode and Effects Analysis is a systematic methodology designed to identify the potential of failure, and causes and effect of failure on a system (Liu, 2016). The principle of FMEA risk assessment is to assess risk in terms of Severity, Occurrence, and Detection level with the current method or process. By using the Pareto principle, the critical value of RPN is determined from 160 and the RSV is determined from 40 (Setchi et al. 2016, Liu 2016). The rating scale for FMEA is shown as table 1, (Sinnott & Towler, 2019):

Table 1. Rating Scale for FMEA

Rating	Severity	Occurrence	Detection
1	Effect is significant	Failure is very unlikely	Current safeguard will always prevent failure mode
4	Minor disruption, possible loss of production	Occasional failure possible	High probability that currents safeguard will detect or prevent
7	Major disruption, possible damage to local equipment	Infrequent failure is likely	Low probability that currents safeguard will detect or prevent
10	Severe disruption, major damage to plant, possible injury to personnel	Failure is very likely or frequent	No current method of detection

3. Methods

The output from Failure Mode & Effect Analysis method in this research is used to preventing unscheduled breakdown and also minimize the fixing cost for unscheduled breakdown so that the company can have more profit. Before assessing the potential failure, this paper measures the correlation between x variable and y variable as table 2 using scatterplot. A scatterplot may be used to depict the shape, direction, and to a lesser extent the strength of the relationship between two variables. In the case of two continuous variables, when both are on at least interval scales of measurement, the direction and strength of the linear relationship between them may be characterized by Pearson correlation coefficient (Weinberg, Harel et al., 2020).

Table 2. Maintenance Variable

Variable x	Variable y
Inspection Follow up %	Physical Availability (PA)
	Mean Time Between Failure (MTBF)
Scheduled Breakdown Hours	Physical Availability (PA)
	Mean Time Between Failure (MTBF)

The correlation in this paper will shows what variable that make performance of the preventive maintenance improving. Besides improving the performance of maintenance minimizing the potential of failure can be done by FMEA method.

Failure Mode and Effect Analysis (FMEA) is a multi-criteria decision making approach to augment the capability of identifying the risk and potential failures (Singh et al., 2020). FMEA assessing principle is using Pareto Principle as the 80/20 rule which critical value of Risk Priority Number set as 160 and value of Risk Score Value set as 40 (Setchi, Howlett, Liu, & Theobald, 2016). FMEA method assessing have three utilization there are severity to rate the significance the failure, occurrence to rate the frequency of failure, and detection to rate the probability of the failure cause. RPN value is given by severity, occurrence, and detection multiply, which generates the criticality of each failure. According (Singh et al., 2020). The RPN and RSV calculation formula are:

$$RPN = S \times O \times D$$

$$RSV = S \times O$$

4. Data Collection

Data collection for this research were using a historical data. Type of data for the correlation analysis are the percentage of inspection follow up, scheduled breakdown hours, the percentage of physical availability, and MTBF. As Table 3 inspection follow up %, physical availability % and MTBF from December 2019-October 2020. Variable x for the percentage of inspection follow up and variable y for percentage of physical availability and MTBF.

Table 3. Percentage of Inspection Follow Up, Percentage of PA and MTBF

Periode	*Inspection Follow Up* %	*Scheduled Breakdown* %	*Physical Availabilty* %
Dec. 2019	26,92	61,89	95,67
Jan. 2020	58,60	82,79	95,11
Feb. 2020	37,36	63,84	95,74
Mar. 2020	53,63	84,69	95,80
Apr. 2020	35,47	77,38	96,30
May 2020	91,48	66,61	96,55
June 2020	54,05	88,55	95,94
July 2020	58,33	81,52	96,17
Aug. 2020	46,60	72,78	95,24
Sep. 2020	52,50	80,23	95,45
Oct. 2020	82,47	80,50	96,47

As Table 4 shows scheduled breakdown hours, percentage of PA, and MTBF that will used to have the type of correlation of 2 variables there are scheduled breakdown hours as variable x with the percentage of PA as variable y and scheduled breakdown hours as variable with MTBF as variable y.

Table 4. Scheduled Breakdown Hours, Percentage of PA, and MTBF

Periode	Scheduled BreakdownHours	Physical Availabilty %	Periode	MTBF
Dec. 2019	243,20	95,11	Jan. 2020	201,27
Jan. 2020	410,85	95,74	Feb. 2020	174,23
Feb. 2020	264,57	95,80	Mar. 2020	202,59
Mar. 2020	345,70	96,30	Apr. 2020	205,62
Apr. 2020	263,12	96,55	May 2020	181,43
May 2020	207,33	95,94	June 2020	357,33
June 2020	331,48	96,17	July 2020	351,24
July 2020	305,42	95,24	Aug. 2020	189,56
Aug. 2020	328,60	95,45	Sep. 2020	170,97
Sep. 2020	320,08	96,47	Oct. 2020	232,19

The components on heavy equipment unit have a common failure or troubleshoot in order to know which components that will be assessed for every potential failure as Table 5 shows a few list of troubleshoot that happens to the unit components.

Table 5. List of Troubleshoot and Its Component, Jan. 2020

Problem	Component	Sub Component	Action
Dump Abnormal	Electrical System	Solenoid	Repair wiring BCV solenoid & T/S
Oil engine leak	Engine	Oil Leaking	fill oil engine and repair cap oil engine
Kebocoran Area Engine	Engine	Hose Coolant	Repair Clamp Hose Thermostat RH Upper, Add Coolant
AC Hot	Air Conditioner	Freon Low	Check & Adjust Freon AC
AC Hot	Air Conditioner	Thermostat	Install & Setting Thermostat AC
Suspension Abnormal & Vessel Oblack	Suspension	Leaking	Levelling Rear Suspension RH LH & Check Vessel Oblack
Hose Grease Leak	Auxiliary Device	Leaking	Repair Hose Grease & Adjustment Front Susp RH LH
Susp Front Drop	Suspension	Leaking	Adjust Front Susp RH dan LH
Ac Hot	Air Conditioner	Compressor	Replace Compressor Ac,Replace dryer,leveling freon,vacum ac
Ac Hot	Air Conditioner	Mechanical AC	Replace Dryer, Replace Condensor, Replace Expantion, Replace Magnet Clutch, Levelling Freon
Ac Hot	Air Conditioner	Leaking	Repair AC System
AC Hot	Air Conditioner	Freon Low	Flushing AC System,Adjust Freon & Adjust Thermostat AC

Table 5. List of Troubleshoot and Its Component, Jan. 2020 (2)

Problem	Component	Sub Component	Action
Oil Engine Leak	Engine	Oil Leaking	Tihtening Coupling Piping by Pass Coolant
Low Power	Engine	Sensor	Clean up sensor commond rail LH and Ground test Unit 1 ret
Engine low power	Engine	Low Power	Replace bolt joint filter fuel,Clean up connector fuel system
Error 03 & Leaking at Piping	Engine	Cooler	Repair & Tightening Coupling Oil Cooler
Fuel Leak	Engine	Leaking	Tightening Fuel piping RH Dump
Oil steering leak	Steering System	Hose Leaking	Replace hose steerimg valve 5 pcs
Low power	Engine	Low Power	Check Fuel Sistem, Ground test
Error engine system	Engine	Electrical	Check wiring speed sensor,test stall
Error Eng System	Electrical System	Sensor	Replace G Sensor, Repair Wiring G Sensor, Kawashima
Can't start	Electrical System	Battery	Repair Terminal Battery
Error 03	Electrical System	Switch	Clean Up Fill Switch Clutch No 3,Tunning Transmission & Groundtest
Engine Oil Pressure On	Engine	Oil Pressure Engine	Repair Connector JC 03
Error Engine System	Engine	Electrical	Repair wiring comman rail pressor sensor LH
AC Hot	Air Conditioner	Freon Low	Adjust freon and thermostart ac
Engine Oil Pressure	Engine	Oil Pressure Engine	Replace sensor engine oil pressure, Replace Compressor AC
Susp Abnormal	Suspension	Leaking	Adjust Front Susp RH

5. Results and Discussion
5.1 Numerical Results
The value of RPN and RSV that have been calculated based on severity, occurrence, and detection level as table 6.

Table 6. RPN and RSV Value

CODE	Component	S	O	D	RPN	RSV
C1	Air Conditioner	1	9	2	18	9
C2	Auxiliary Device	8	1	7	56	8
C3	Brake System	10	5	8	400	50
C4	Electrical System	5	10	10	500	50
C5	Engine	8	8	4	256	64
C6	Frame & Chasis	3	7	3	63	21
C7	Hydraulic System	7	3	5	105	21
C8	Steering System	9	2	4	72	18
C9	Suspension	4	6	1	24	24
C10	Transmissions	6	4	9	216	24

The potential failure mode that needs to be prioritize from each components according to Pareto Principle as Table 7.

Table 7. Potential Failure Mode

CODE	Potential Failure Mode	Potential Effect of Failure
C3	- Hose Brake & Oil Leaking - Mechanical Brake Worn Out - Switch & Sensor Brake Troubleshoot - Wiring Troubleshoot	- Unconttrolled unit speed - Potentially causing an accident or incident
C4	- Alternator Malfunction - Battery Not Charge - Error, Switch & Solenoid Brake Troubleshoot - Wiring Troubleshoot	- Unit failure - Electrical error potentially causing Electrical Alternator malfunction - Short circuit (Fire incident)
C5	-Water Coolant Leaking - Oil & Fuel Leaking - Low Power & Filter Blocking - Fuel Pump Troubleshoot - Electrical Engine Troubleshoot	- Water Coolant leaking is causing Engine overheating - Engine jammed - Filter blocking potentially causing Engine power decreasing - Oil leak can cause engine part worn out

As Table 8 shows the potential cause and the prevention action that need to be done.

Table 8 Potential Cause and Preventive action

CODE	Potential Cause	Preventation action
C3	- Unidentified leaking leakage - Inconsistent during system adjustment - Failed to identify the lifetime of Sensor, Switch or Solenoid - Switch and Wire Electric System not installed properly (wire clamp missing or loose and messy layout)	- Perform a regular inspection of brake system components - Perform a backlog management program and calculate the lifetime of brake system components - scheduled a regular inspection for brake adjustmen system
C4	- Irregular battery replacement - Charging system function has not been checked - Has not been repaired for a long time since it's been damage - Switch and Wire Electric System not installed properly (wire clamp missing or loose and messy layout) - Lifetime has not been identified	- Perform a test for electrical system during regular inspection - Protective equipments need to be made to protect the electrical components from potential dust exposure, water or humidity - Perform a backlog management program to list the failure finding on regular inspection and perform a scheduled replacement and maintenance
C5	- Coolant leakage happens caused by hose that has not been checked - Undamped vibration exposure can cause pipe cracked - fuel liquid is not optimal (fuel has been contaminated) - Fuel pump lifetime has not been identified - Lack of engine maintenance	- Review the list of failure finding during inspection - Perform a backlog management to collect notes of potential failure on PS 250, PS 500 etc maintenance - Check the hygiene of lubricant liquid health and replace the old lubricant with the new lubricant and also clean the filter - Careful inspection on the electrical system engine

5.2 Graphical Results

The direction and strength of four correlation between variable x and variable y as Figure 1 and Figure 2.

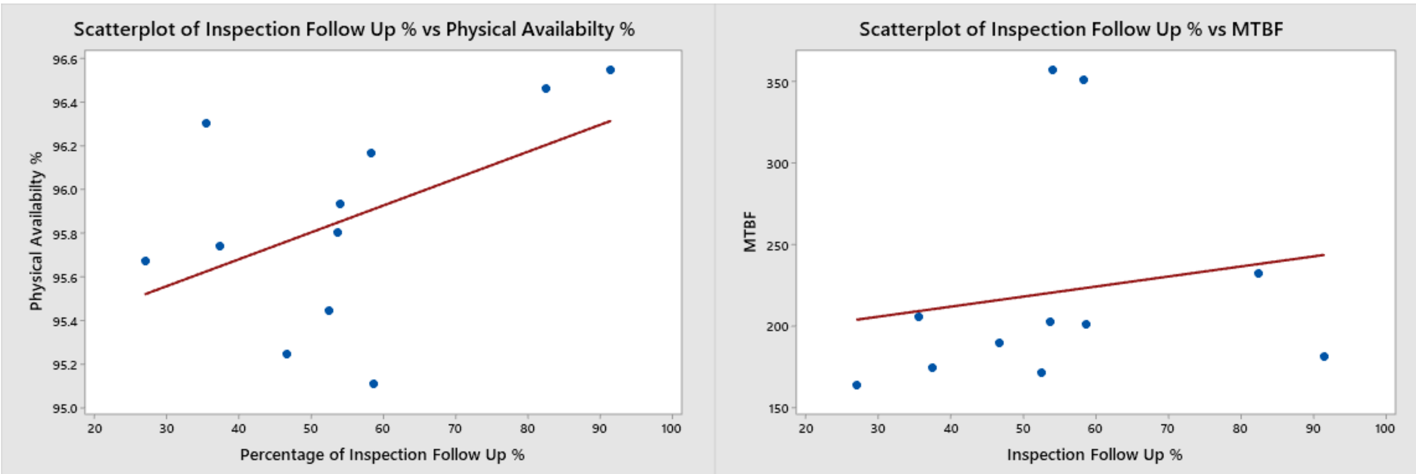

Figure 1. Correlation between Inspection Follow Up % Variable and PA % & MTBF Variable

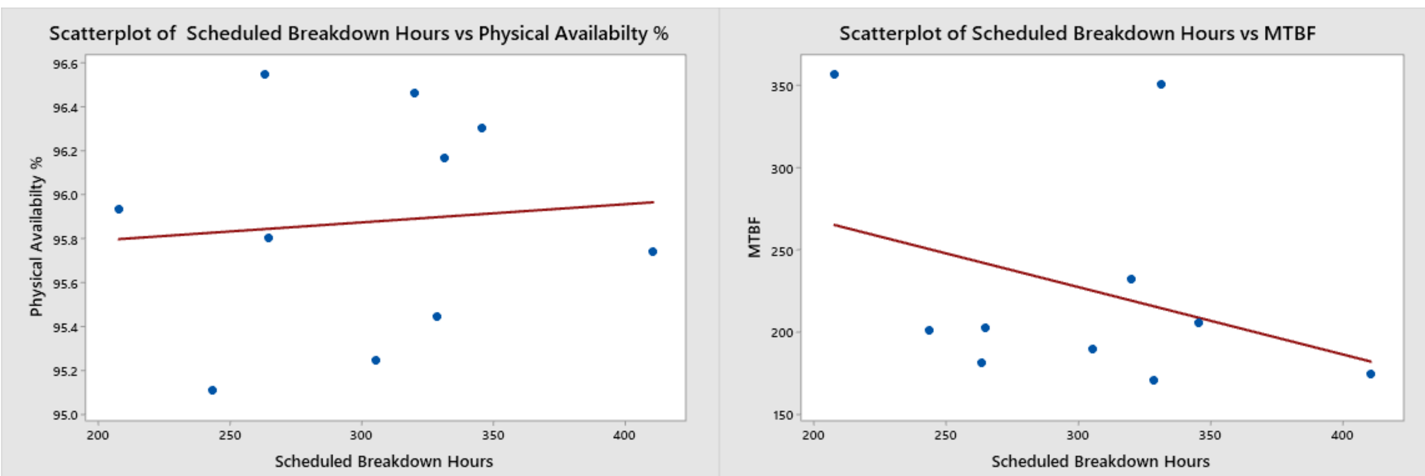

Figure 2. Correlation between Scheduled Breakdown Hours Variable and PA % & MTBF Variable

To accurately obtain the correlation between two variables, further statistical analysis is necessary. The Pearson correlation coefficient test from scatterplot as table 9.

Table 9. Pairwise Pearson Correlations

Variable x	Variable y	Correlation	95% CI for ρ	P-Value
Percentage Follow Up Inspection	Physical Availability	0.490	(-0.155, 0.842)	0.126
Percentage Follow Up Inspection	MTBF	0.172	(-0.477, 0.699)	0.614
Scheduled Breakdown Hours	Physical Availability	0.097	(-0.568, 0.685)	0.791
Scheduled Breakdown Hours	MTBF	-0.345	(-0.801, 0.364)	0.329

The Pearson correlation coefficient of inspection follow up % and PA is 0.49 and its 95% CI for ρ is (-0.155, 0.842) with p-value 0.126 which is more than 0.01 so that the direction and strength on the scatterplot is significant. Meaning that the correlation between inspection follow up percentage with Physical Availability percentage level shows a moderate positive correlation. The Pearson correlation coefficient of inspection follow up % a MTBF is 0.172 and its 95% CI for ρ is (-0.477, 0.699) with p-value 0.614 which is more than 0.01 so that the direction and strength on the scatterplot is significant. It means there is a weak positive correlation between percentage of inspection follow up and MTBF.

The Pearson correlation coefficient for scheduled breakdown hours and PA is 0.097 and its 95% CI for ρ is (-0.568, 0.685) with p-value 0.791 which is more than 0.01 so that the direction and strength on the scatterplot is significant. Meaning there are no correlation between scheduled breakdown hours and PA. The Pearson correlation coefficient for scheduled breakdown hours and MTBF is -0.345 and its 95% CI for ρ is (-0.801, 0.364) with p-value 0.329 which is more than 0.01 so that the direction and strength on the scatterplot is significant. It means that the correlation between scheduled breakdown hours and MTBF on scatterplot diagram shows a weak negative correlation.

The value of RPN and RSV is needed to be evaluate by Pareto chart scatterplot. The principle of Pareto can be calculate using Minitab software for 80/20 rule. The scatterplot of RPN and RSV values are made to have the critical components that need to be prioritize. The scatterplot is using interpolated calculation to determine the area of critical level. As Figure 3 shown that there are 3 components that needs to be prioritize and make the preventive action. The 3 components are electrical system, brake system, and engine. Quadrant that located at the top right should consists of the variable that need to be prioritize because failure potentially occurs all the time. The top 3 RPN value are 500, 400, and 256 and the RSV value are 50, 50, and 64.

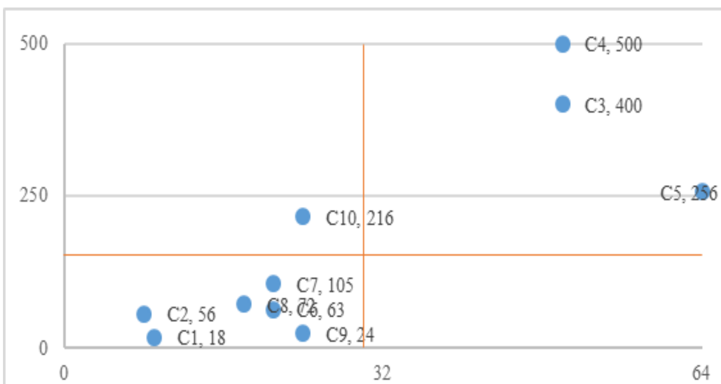

Figure 3. RPN and RSV Scatterplot

The component that located at the top left quadrant is C10. The top left quadrant is consists of a failure that has often occurred. It will not be a big problem for the company if it's happen but still make a little cost of failure. The bottom left quadrant consists of failure that does not often to occur so the company sometimes ignore the fatality. Components of C7, C8, C6, C2, C9, and C1 are filling the bottom left quadrant. The bottom right quadrant is filled with the failure that rarely occurs, but when it occurs it will make a big lost or effect to the company.

6. Conclusion

The correlation between inspection follow up percentage with Physical Availability percentage level shows a moderate positive correlation known from the Pearson correlation coefficient which has value r = 0.49. And the weak positive correlation between percentage of inspection follow up and MTBF which has value r = 0.17 of Pearson correlation coefficient. Meaning sometimes if the percentage of inspection follow up is increasing so is the percentage of PA level and also with MTBF performance. The correlation between two variables can be roughly judged by the scatterplot

Scheduled breakdown hours variable have no correlation with the percentage of PA level which can be seen from the Pearson correlation coefficient value r = 0.09. The correlation between scheduled breakdown hours and MTBF on scatterplot diagram shows a weak negative correlation as the value of Pearson correlation coefficient shows r = - 0.34. It means if the value of scheduled breakdown hours increases then the value of MTBF decreases.

The Risk Priority Number versus Risk Severity Number four quadrant diagram selecting three components that must be prioritized. The three components are electrical system component with 500 for RPN value and 50 for RSV value, brake component with 400 for RPN value and 50 for RSV value, engine component with 256 for RPN value and 64 for RSV value. The overall mitigation that has been made for those three components are: Maintaining the components condition by doing a whole examination for the components and measuring the lifetime of the component.

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Biographies

Salmaa Nabiilah A is an undergraduated student at Bina Nusantara Univeristy majoring Industrial Engineering specifically Supply Chain Management stream.

Ir. Fransisca Dini Ariyanti is a lecturer at Industrial Engineering Bina Nusantara University. She has earned her Master degree of Industrial Engineering at University of Indonesia. Her research covers several fields, supply chain, quality and project management.