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Application of *the Failure Mode And Effect Analysis* (FMEA) Method in the Shipping Industry in Identifying Potential Failure of Main Engine Components (Case Study on the Xyz Ship)

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Abstract

A ship's main engine plays a crucial role in supporting the smooth operation of the vessel. Failure in the components of this engine can have serious consequences, both in terms of safety and economics. This study found that fuel pipe leakage in the main engine could trigger fires or explosions, as well as increase the risk of accidents due to the ship losing control. From an economic perspective, this failure causes operational downtime, high repair costs, and losses due to shipment delays. To identify potential failures and assess their risk levels, this research employs the Failure Mode and Effect Analysis (FMEA) method. Data for the study were obtained through interviews with the chief engineer, machinists, and technicians and analysis of historical engine failure records. The parameters of Severity (S), Occurrence (O), and Detection (D) were used to calculate the Risk Priority Number (RPN). The results show that fuel pipe leakage has the highest RPN (405), which implicates the risks of fire, fuel supply disruptions, and potential environmental contamination. It is recommended to conduct regular inspections, use corrosion-resistant pipe materials, and install leak detection sensors to mitigate these risks. Additionally, damage to the turbocharger rotor (RPN 245) affects engine power and increases emissions. Therefore, regular cleaning, checking the condition of lubricants, and using high-quality air filtration systems are recommended. Mechanical damage to the intake valve (RPN 224) was also found to reduce combustion efficiency and engine performance. This can be resolved through scheduled replacements, regular lubrication, and visual inspections..

Keywords: FMEA, Parent Engine, Potential Failure, Ship, Risk Priority Number.

1. INTRODUCTION

Applying failure mode and effect analysis (FMEA) in the maritime industry, especially to identify potential failures in the main engines of ships, is essential to improving safety and operational efficiency. FMEA systematically evaluates potential failure modes, causes, and effects, allowing for prioritized corrective action. Steps in the implementation of FMEA include component identification involving all important components of the ship's main engine, including pumps, valves, and sensors (Crawley, 2020). Each component is analyzed for possible failure modes such as mechanical wear, electrical faults, or electrocutions (Mencik, 2016). Risk assessments are also carried out to obtain the severity, occurrence, and detection of each failure mode is assessed to calculate the Risk Priority Number (RPN), which helps prioritize risks (Häring, 2021) (Menčík, 2016). Based on the RPN, appropriate corrective actions are recommended to reduce the identified risks (Crawley, 2020). The main engine is the heart of a ship's operations, driving the propellers that allow the ship to move. The operational conditions of ships working in extreme environments such as the open sea increase the risk of damage to engine components. Failure in the parent engine not only causes significant operational downtime but can also increase the risk of accidents and major losses in terms of cost and safety. Therefore, proper maintenance and early identification of potential failures are essential to avoid untoward events (Saputra et al., 2019). Therefore, risk management of potential master engine failures is essential to ensure operational sustainability. This study uses the FMEA method to assist in identifying potential failures in the Xyz Ship aircraft carrier components that are most susceptible to failure and provide guidance to minimize the risk of failure (Islam et al., 2019). FMEA allows the evaluation of failure modes based on impact severity, frequency of occurrence, and detection rate. From this, risk priority can be obtained in the form of a Risk Priority Number (RPN), which can be used to guide preventive measures.

Applying the Failure Mode and Effect Analysis (FMEA) method in the payment industry is essential to identify potential ship engine failures. FMEA assists in analyzing risks and prioritizing mitigation actions based on severity, frequency, and failure detection capabilities. FMEA allows the identification of various failure modes in the parent engine, such as damage to the exhaust, fuel, and cooling systems (Arifin et al., 2020). Each failure mode is evaluated based on its impact on the ship's operations, which helps in understanding the consequences of each chamber (Crawley, 2020). This method uses Risk Priority Numbers (RPNs) to measure and prioritize risks by shifting severity, frequency, and detection values (Saputro & Basuki, 2022) (Crawley, 2020). For example, in the analysis of lubricating systems, components such as oil pumps and filters have a high-risk value, indicating the need for more attention (Arifin et al., 2020). Based on the results of the analysis, appropriate maintenance measures, such as preventive and corrective maintenance, can be determined to prevent future failures (Arifin et al., 2020). FMEA also assists in formulating action plans to reduce risk and improve safety and operational efficiency (Sartor & Cescon, 2019).

Although FMEA offers a systematic approach to identifying and managing risks, there are challenges in its implementation, such as the need for accurate data and multidisciplinary team insights. This shows that while FMEA is effective, its success depends heavily on the collaboration and commitment of all parties involved. FMEA helps identify various failure modes in the parent engine, such as mechanical components or cooling system failures. Each mode of failure is evaluated based on its impact on the ship's operations, including potential accidents or financial losses. Each potential failure is assessed using an RPN, which combines severity, likelihood of occurrence, and detection capabilities. For example, a failure in an engine's lubrication system can have a high RPN, indicating the need for successful corrective action (Nazar et al., 2024). Based on the analysis results, corrective actions can be proposed, such as increased training for operators and regular maintenance of the machine. Implementing this measure aims to reduce the risk of failure and improve operational efficiency (Rayendra & Resfi, 2024).

The development of marine transportation brings various challenges, particularly in managing waste produced by ships. Waste incineration has been identified as an effective solution to minimize on-board waste and ensure proper disposal at designated facilities upon arrival at the destination port. While incineration can also be carried out at sea under specific regulations, it poses significant risks of workplace accidents. This study aimed to identify potential risk factors related to workplace accidents during waste incineration activities on ships using the Failure Mode and Effects Analysis (FMEA) method. The study also evaluated and analyzed occupational accident risk levels to develop measures for minimizing these incidents. The FMEA analysis revealed that the highest risk of workplace accidents involved hand injuries, with a Risk Priority Number (RPN) of 211.58 or 21.1% during waste incineration activities in the ship's incinerator. (Kuncowati et al., 2024).

2. METHODOLOGY

In this study, the author uses the FMEA method as the main approach to identify the failure of the main engine components. The data used in this study were collected through direct inspections, interviews with KKM, ship engine engineers and technicians, questionnaires, and historical data on the mother engine failure on XYZ ships.

The object of this research was carried out on the XYZ ship's main engine, a type of 4-stroke engine with a closed cooling system with seawater and freshwater media. This machine is used in open sea conditions with high workloads, especially when transporting heavy loads on long trips. The engine data analyzed consists of the main components: the turbocharger, lubrication system, fuel pipe, water pump, injector, intake valve, crankshaft, cylinder liner, and electrical system. Piston, oil pump, and cooling system. Then, the data of the engine components are identified and collected data to be analyzed by *the Failure Mode and Effect Analysis* (FMEA) approach method to obtain *a Risk Priority Number* (RPN) to find the main factors causing engine failure or damage and how these factors affect the performance of the engine on the ship.

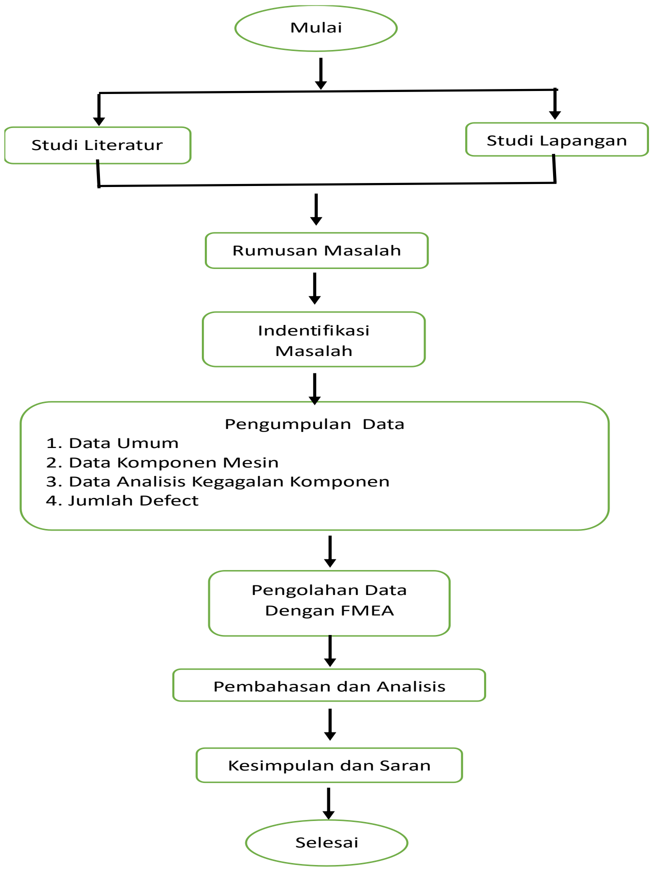

Figure 1. Flow Chart Research

Failure Mode and Effect Analysis (FMEA) aims to identify the sources of problems and the root causes of potential failures in certain systems or components (Daryanto & Minto Basuki, 2023). This FMEA method is beneficial for detecting and analyzing various forms of failure and their consequences, with the ultimate goal of preventing or reducing the risk of such failure.

In the implementation of FMEA, the assessment is focused on three main components that play an important role in determining the priority of disruption risk, namely Occurrence (O) to measure how often certain disturbances or problems arise that can cause failures in the operation of the system. Assessment of this aspect makes it possible to estimate the frequency of failure occurrence. Severity (S) is used to assess the severity or impact of failure on the overall machine system. The greater the effect of the damage caused, the higher the priority level to prevent or overcome this failure. Severity helps highlight the failure with the most significant consequences; Detection (D) indicates the system's ability to detect potential failures before they occur. This aspect aims to assess the extent to which early detection efforts can be made so that the risk of the impact of failure can be minimized.

After the three components (O, S, and D) are assessed, the next step is calculating the *Risk Priority Number* (RPN). RPN is a risk priority value obtained by multiplying the values of Occurrence (O), Severity (S), and Detection (D). This RPN value is then used to determine the priority order in dealing with potential failures, where a higher RPN value signals greater risk and requires more immediate preventive measures. This method is very useful in analyzing and preventing potential failures in the ship's main engine or other equipment to maintain the smooth and safe operation of the ship. To calculate the Risk *Priority Number* (RPN) value of each failure event of XYZ aircraft carrier components with the formula:

$$RPN = S \times O \times D \quad (1)$$

After obtaining the RPN value for each equipment failure risk event, the percentage of failure risk events in the ship's main engine components can be determined. The percentage of failure risk events is calculated as a comparison between the RPN of each risk event and the total RPN, then multiplied by 100% (Daryanto & Minto Basuki, 2023). The calculation formula is as follows:

$$Prosentase\ kejadian\ keggagalan = \frac{RPN\ Kejadian\ kegagalan}{Total\ RPN\ keseluruhan}\ x\ 100\% \quad (2)$$

Table 1. Main Engine Specifications

Maker	Hanshin Diesel Works. LTD.
Type	LH 46 LA
Engine Number	LH 46 L-5
Continuous Max power	4500 PS
Engine Speed	220 RPM
Number Of Cylinders	6
Cylinder Bore x Stroke	460 x 880 mm
Total Weight	78,000 kg
Date of manufacture	06 - 1996

The severity of the hazard, represented by the severity (S), describes how serious the hazard is when the aircraft carrier component system is operating. This severity scale is presented in Table 2.

Table 2. Failure rate and hazard severity

Level	Failure Rate	Impact on Systems/Processes
10	**Catastrophic Failure**: A serious failure resulting in severe damage and fatal accidents.	It results in death or severe injury, destruction of the system, major financial loss, or fatal accident.
9	**Critical Failure**: A serious failure that causes major disruption or significant loss.	It results in serious injury or fatal illness or major loss to major assets or systems.
8	**Major Failure**: A failure that results in a major loss of operations, products, or services.	This results in major damage to the system, operational disruption, and large but not fatal losses.
7	**Serious Failures**: Significant failures in performance with a large operational impact.	This causes major losses to system performance and requires immediate repairs without an immediate safety threat.
6	**Significant Failure**: An interruption that causes a substantial performance loss or a product failure.	This results in a system or product failing to function according to specifications and requiring immediate action for repair.
5	**Moderate Failure**: Failure causes an acceptable performance loss but can be corrected immediately.	Performance decreases or decreases, and corrective action is required but does not result in serious damage.
4	**Minor Failures**: Minor failures have a relatively limited impact on the operation or functioning of the system.	Reduction in product performance or quality does not have a significant effect on the overall system.
3	**Tolerable Failures**: Minor glitches that do not affect the main performance of the system.	Minor tolerable issues with little or no impact on system function or performance.
2	**Very Small Failures**: Disruptions or defects that are barely visible and do not affect operations.	It has a small impact that hardly affects performance, quality, or safety.
1	**No Impact**: There is no impact or loss due to failure.	Failure does not affect the system or the product as a whole.

Source: Primary Data, 2024

The Occurrence Frequency represented by Occurrence (O) indicates how often a component failure occurs to the point of causing a system failure or indicates the chance of a failure. This Occurrence Scale is presented in Table 3.

Table 3. Frequency of Failure Events

Occurrence Scale	Frequency of occurrence	Information
10	Very Often (> 1 time per day)	Failure modes occur almost always, very often, during operations.
9	Frequent (1 time per day)	Failure modes occur daily, often affecting the operation of the machine.
8	Quite Often (1 time per week)	Failure mode occurs several times a week.
7	Quite High (1 time per month)	Failure mode occurs once a month.
6	Moderate (1 time per 3 months)	Failure mode occurs about one time in 3 months.
5	Rare (1 time per year)	Failure mode occurs about once a year.
4	Very Rare (1 time every 1-3 years)	Failure mode occurs every 1 to 3 years.
3	Rarely (1 time every 3-5 years)	Failure mode occurs very rarely, perhaps only every 3 to 5 years.
2	Rarely (1 time every 5-10 years)	Failure mode is very rare, perhaps only in 5 to 10 years.
1	Very Rare (1 time in more than 10 years)	Failure mode is rarely occurring, more than once every 10 years.

Source: Primary Data, 2024

The Detection Rate represented by Detection (D) indicates the extent to which failures can be identified before or just when they are about to occur. This assessment is very subjective and depends on the experience of the resource persons in the field. The Detection Scale is presented in Table 4.

Table 4. Detection Rate and Failure Criteria

Detection Scale	Detection Rate	Criterion
10	Highly undetectable	Failure is almost impossible to detect before it causes complete damage.
9	Very Difficult to Detect	Failure is very difficult to detect; it may be detected after a significant impact.
8	Difficult to Detect	Detection is only possible with very strict controls and intensive inspections.
7	Limited Possibilities	Detection is possible, but only in a few situations or after an impact has occurred.
6	Moderate Detection	It is detected only with certain controls or procedures but is not always effective.
5	Sometimes Detected	Detection is possible with regular inspections, but it is not always reliable.
4	Quite Easy to Detect	Regular manual monitoring or inspection systems can usually detect failures.
3	Easy to Detect	Failures are often detected easily by both automated systems and operators.
2	Highly Detectable	Almost all failures can be detected before serious impacts occur.
1	Detected	Failures are detected through automatic monitoring or control systems.

Source: Primary Data, 2024

3. RESULTS AND DISCUSSION

Based on the data collected through inspections, interviews, filling out questionnaires with the head of the engine room (KKM), the engineer, the ship's engine technician, and historical data on the main engine failure on the XYZ ship, an overview of the characteristics of the results *of the Severity* (S) assessment and risk evaluation through *Failure Mode and Effect Analysis* (FMEA) analysis of the malfunction of the main engine components on the XYZ ship is shown in table 5.

Table 5. Assessment of failure level and severity of hazard (severity).

No.	Komponen Mesin	Mode Kegagalan	Dampak Terhadap Sistem	Severity (Skala 1-10)
1	Turbocharger	Kerusakan rotor	Penurunan daya mesin secara drastis	7
2	Sistem Pelumasan	Kebocoran oli	Overheating dan kerusakan komponen lain	8
3	Pipa Bahan Bakar	Kebocoran pada pipa	Kinerja bahan bakar tidak stabil, potensi kebakaran	9
4	Pompa Air	Pompa tidak bekerja	Pendinginan mesin tidak berfungsi, overheating	8
5	Injektor	Injektor tersumbat	Pembakaran tidak sempurna, penurunan efisiensi	6
6	Sistem Pendingin	Kebocoran pipa pendingin	Overheating mesin	8
7	Katup Intake	Kerusakan mekanis pada katup	Mesin tidak dapat bekerja pada performa optimal	7
8	Crankshaft	Keausan crankshaft	Getaran berlebihan, kerusakan bearing	9
9	Cylinder Liner	Keausan silinder	Penurunan kompresi, penurunan performa	6
10	Sistem Kelistrikan	Gangguan pada wiring	Kegagalan sistem kontrol, potensi korsleting	9

Source: Primary data processed, 2024

Referring to the data collected through inspections, interviews, filling out questionnaires with the head of the engine room (KKM), engineers, ship engine technicians, and historical data on the failure of the main engine components on the XYZ ship, an overview of the characteristics of the results *of the Occurrence* (O) assessment and risk evaluation through *Failure Mode and Effect Analysis* (FMEA) analysis of the malfunction of the main engine components is shown in table 6.

Table 6. Assessment of Frequency of Failure Occurrence

Engine Components	Failure Mode	Frequency of occurrence	Occurrence (Scale 1-10)
Turbocharger	Rotor malfunction	2-3 times a year	5
Lubrication System	Oil leakage	Once every 6 months	6
Fuel Pipeline	Pipe leaks	Once a year	5
Water Pump	Pump not working	1 time in 2 years	4
Injector	Clogged injectors	3-4 times a year	7
Cooling System	Cooling pipe leaks	1 time per year	5
Intake Valve	Mechanical damage to the valve	1 time every 2 years	4
Crankshaft	Crankshaft wear	1 time every 3 years	3
Cylinder Liner	Cylinder wear	1 time in 5 years	3
Electrical System	Wiring interference	1 time every 2-3 years	4

Source: Primary data processed, 2024

From the results of data collection through inspections, interviews, filling out questionnaires with the head of the engine room (KKM), engineers, and ship engine technicians, as well as historical data on the failure of the main engine components on the XYZ ship, a *detection* assessment (O) using *Failure Mode and Effect Analysis* (FMEA) on the malfunction of the main engine components was obtained, which is presented in Table 7.

Table 7. Failure Mode Assessment of Machine Component Detection

No.	Engine Components	Failure Mode	Possible Detection	Detection (Scale 1-10)
1	Turbocharger	Rotor malfunction	Detection is difficult; only detected when there is a power drop	7
2	Lubrication System	Oil leakage	Detected quite easily through regular inspections	4
3	Fuel Pipeline	Pipe leaks	Very difficult to detect, often found after damage	9
4	Water Pump	Pump not working	Detected through a disturbed cooling system	6
5	Injector	Clogged injectors	Easy to detect with engine performance monitoring	3
6	Cooling System	Cooling pipe leaks	Quite easy to detect through temperature sensors and inspections	4
7	Intake Valve	Mechanical damage to the valve	Difficult to detect, except during thorough inspection	8
8	Crankshaft	Crankshaft wear	Difficult to detect except through vibration analysis	8
9	Cylinder Liner	Cylinder wear	Easily detected through compression pressure drop	3
10	Electrical System	Wiring interference	Moderate detection, detected after symptoms of electrical disturbances	6

Source: Primary data processed, 2024

This table provides a scale that shows how likely a failure can be detected before it causes serious losses or problems. Good detection allows for quick preventive action or correction, while poor detection increases the risk of failure without warning.

3.1. Failure Mode Identification and FMEA Assessment

From the three assessments in Tables 5, 6, and 7, the RPN assessment was carried out by multiplying the values of Severity (S), Occurrence (O), and Detection (D) to get the Risk Priority Number (RPN) value of each component, which is presented in Table 8.

Table 8. Identity Assessment of Potential Failure of Ship Parent Engine Components (RPN)

No	Komponen	Fungsi	Failure mode (mode kegagalan)	Failure mechanism (mekanisme kegagalan)	Effect Failure (pengaruh kegagalan)	Failure Detection (deteksi kegagalan)	Risk reducing measures	S	O	D	RPN
1	Turbocharger	Meningkatkan tekanan udara ke mesin	Kerusakan rotor	Penumpukan kotoran, keausan pada bearing	Penurunan daya mesin, performa tidak optimal	Inspeksi getaran dan suara mesin	Pembersihan rutin, pemeriksaan pelumas	7	5	7	245
2	Sistem Pelumasan	Melumasi komponen mesin	Kebocoran oli	Kerusakan pipa atau segel pelumas	Overheating, kerusakan komponen lain	Inspeksi visual dan pemantauan tekanan pelumas	Penggantian segel, pemasangan sensor kebocoran	8	6	4	192
3	Pipa Bahan Bakar	Menyalurkan bahan bakar ke mesin	Kebocoran pipa	Korosi atau kerusakan fisik	Ketidakstabilan suplai bahan bakar, potensi kebakaran	Deteksi dengan inspeksi visual, sensor kebocoran	Penggantian berkala, inspeksi visual	9	5	9	405
4	Pompa Air	Mendistribusikan air pendingin	Pompa tidak bekerja	Kerusakan impeller, motor rusak	Overheating mesin	Pemantauan suhu, inspeksi pendingin	Pemeriksaan berkala, perbaikan komponen	8	4	6	192
5	Injektor	Menginjeksikan bahan bakar ke silinder	Injektor tersumbat	Akumulasi karbon, kotoran	Pembakaran tidak sempurna, efisiensi menurun	Monitoring performa mesin, inspeksi nozzle	Pembersihan nozzle, penggunaan bahan bakar bersih	6	7	3	126
6	Sistem Pendingin	Mendinginkan komponen mesin	Kebocoran pipa pendingin	Korosi, keretakan pada sambungan	Mesin overheat	Sensor suhu, pemeriksaan visual	Penggantian pipa, perawatan preventif	8	5	4	160
7	Katup Intake	Mengatur aliran udara masuk ke mesin	Kerusakan mekanis pada katup	Keausan, kerusakan pegas	Performa mesin menurun	Pemeriksaan fisik dan endoskopi	Penggantian katup, pelumasan berkala	7	4	8	224
8	Crankshaft	Mengubah gerakan linier ke rotasi	Keausan crankshaft	Keausan akibat gesekan dan getaran	Getaran berlebih, kerusakan pada bearing	Analisis getaran	Penggantian oli, kontrol beban mesin	9	3	8	216
9	Cylinder Liner	Menjaga kompresi mesin	Keausan silinder	Gesekan berlebih, kualitas pelumas buruk	Penurunan kompresi, performa mesin menurun	Pengukuran tekanan kompresi	Pelumasan berkala, pemeriksaan visual	6	3	3	54
10	Sistem Kelistrikan	Mengontrol sistem kelistrikan mesin	Gangguan pada wiring	Kabel putus, korosi pada konektor	Kegagalan kontrol, potensi korsleting	Deteksi melalui tes kelistrikan	Isolasi kabel, pengecekan koneksi listrik	9	4	6	216

Source: Primary data processed, 2024

After getting the RPN value of each component shown in Table 8, determine the percentage risk of failure rate of the parent engine component based on the comparison of the number of RPN. The amount of risk of failure of the parent engine component with the total RPN multiplied by 100% can be seen in Table 9.

Table 9. Percentage of Identification of the Risk of Failure of Machine Components

It	Engine Components	S	O	D	RPN	Percentage (%)
1	Fuel Pipeline	9	5	9	405	19,95
2	Turbocharger	7	5	7	245	12,07
3	Intake Valve	7	4	8	224	11,03
4	Crankshaft	9	3	8	216	10,64
5	Electrical System	9	4	6	216	10,64
6	Lubrication System	8	6	4	192	9,46
7	Water Pump	8	4	6	192	9,46
8	Injector	6	7	3	126	6,21
9	Cooling System	8	5	4	160	7,88
10	Cylinder Liner	6	3	3	54	2,66

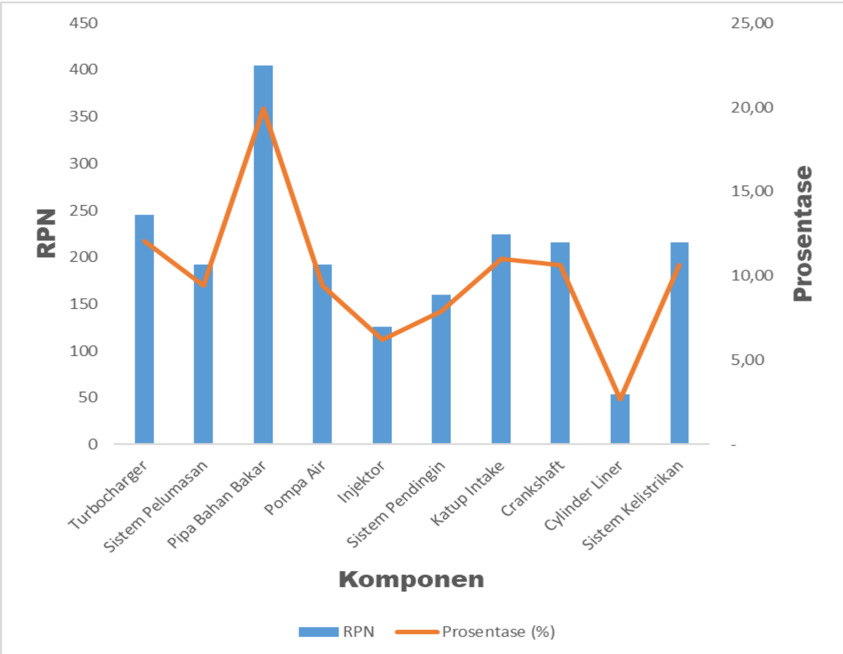

Figure 2. Component Failure Rate based on Percentage and RPN

Based on identifying the percentage risk of malfunction of Xyz aircraft carrier components, it is known that the first highest risk factor is in fuel pipeline components, with a percentage of 20% and an RPN value of 405. This occurs because leaks caused by corrosion and physical damage to the pipeline, resulting in instability of fuel supply, are identified as potentially disrupting the combustion process, decreasing engine performance, and causing a very dangerous fire risk. The second highest factor is the turbocharger engine component, with a percentage of 12% and an RPN value of 245. This occurs due to the build-up of dirt and wear on the bearings due to improper lubricants or poor air quality. Dirt can enter the turbocharger and cause damage to the rotor. It impacts decreasing engine power because a damaged turbocharger cannot increase the air pressure entering the combustion chamber.

4. CONCLUSION

This study has successfully identified potential failures in the Xyz aircraft carrier by applying *the Failure Mode and Effect Analysis* (FMEA) method. The most critical failure mode identified was the fuel pipe component, with the highest value of 405 RPN with a failure percentage of 20%, followed by the turbocharger component with a value of 245 RPN at a percentage of 12%, and the intake valve component with 224 RPN with a known failure percentage of 11%. Based on the results of the identification using *the Failure Mode and Effect Analysis* (FMEA*)* method, preventive measures are recommended, including maintenance, periodic replacement, stricter visual inspections of fuel pipeline components and routine cleaning as well as lubricant checks on turbochargers, as well as valve replacement, periodic lubrication of intake valve components. The application of FMEA in this study has proven to be effective in identifying the most risky failure modes and assisting in developing a more efficient maintenance strategy to reduce the risk of failure in the main engine components on the Xyz Ship.

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