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ANALYSIS OF MAIN ENGINE MAINTENANCE FOR THE VESSEL TB KARYA PACIFIC 2203 USING FAILURE MODE AND EFFECTS ANALYSIS (FMEA) AND RELIABILITY CENTERED MAINTENANCE (RCM) METHODS

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Abstract

A maintenance system oriented solely toward repairs after a breakdown occurs—known as corrective maintenance—often leads to significant downtime and financial losses for a company. Consequently, there is a need for a maintenance strategy capable of identifying critical components and determining appropriate maintenance actions before failures occur. The Failure Mode and Effects Analysis (FMEA) method is widely used to identify failure modes and establish risk priorities for ship machinery components based on their Risk Priority Number (RPN), while Reliability Centered Maintenance (RCM) is employed to define maintenance strategies based on component functions and the consequences of failure. However, research integrating both methods—specifically using actual failure and maintenance data from the main engines of tugboats—remains limited. Therefore, this study proposes an integration of FMEA and RCM. Utilizing a quantitative descriptive approach through a case study of the main engine of the tugboat TB Karya Pacific 2203, this research aims to identify component failure modes, determine risk priority levels via FMEA, and establish maintenance strategies using RCM. The main engine component with the highest RPN (224) is the injector. The recommended maintenance strategies include "Condition-Directed Maintenance" for the injector, seawater cooling pump, and turbocharger, as well as "Condition-Directed Maintenance" for the fuel filter.

Keywords: FMEA, RCM, Machine maintenance

INTRODUCTION

In the shipping industry, the operational success of a ship is greatly influenced by the performance of the main engine as the main power source for the ship's propulsion. Main engines that operate continuously can experience deterioration (the process of gradual decline in the condition, quality, or function of an engine due to use, friction, age, or the environment), which impacts engine performance. Therefore, proper engine condition monitoring and maintenance are necessary (Tran & Kim, 2023). Main engine maintenance activities are a very important factor in ensuring ship operations, shipping safety, increasing equipment reliability, and reducing operational costs due to damage to engine components. Maintenance systems that are only oriented towards repairs after damage occurs (*corrective maintenance*) often result in high *downtime* and incur losses for the company. Therefore, a maintenance strategy is needed that can identify critical components and determine appropriate maintenance actions before failure occurs (ABS, 2022).

Main engine failure analysis is crucial as a basis for developing a ship maintenance program (Busse et al., 2023). One method used for engine failure analysis is the *Failure Mode and Effects Analysis* (FMEA) method, which is a method used to identify various possible failures in a system, analyze their impact on operations, and determine the risk level based on the parameters of *Severity* (S), *Occurrence* (O), and *Detection* (D). The results of *the Risk Priority Number* (RPN) calculation from the FMEA method can be used as a basis for determining repair and maintenance priorities for components with the highest risk level. Planned and reliability-based maintenance is essential to reduce the risk of main engine damage and improve ship operational safety (Yaqin et al., 2020; Daryanto, 2024). Meanwhile, a method widely used in modern maintenance management systems is *Reliability-centered maintenance* (RCM), which uses a systematic approach aimed at determining maintenance needs based on equipment function, failure modes, causes of failure, and the consequences. The application of the

RCM method can help companies in determining maintenance priorities so that available resources can be used more effectively and efficiently (Azhari et al., 2024).

Yaqin et al. (2020) conducted a study on the maintenance risks of the KM. Sidomulyo main engine's fuel system using the FMEA method. The study identified components with a high risk of failure based on their RPN values. The results showed that *the injector* had an RPN of 192, while *the fuel filter* had an RPN of 168. Both components were maintenance priorities. Maintenance recommendations included checking the fuel condition in *the injector* and cleaning deposits in *the fuel filter* .

Research conducted by Indriyani and Dwisetiono (2021) analyzed the failure and handling of marine diesel engine lubrication system components using FMEA. The lubrication system is considered a critical support system because lubrication failure can lead to engine failure. FMEA is used to identify failures in each component and determine maintenance strategies and priorities.

Siahaan et al. (2025) analyzed the maintenance strategy for centrifugal pumps in the main engine cooling system of fishing vessels using the FMEA method. The researchers identified seven main centrifugal pump components and eleven potential failure modes. Some failures could potentially cause serious damage to the pump and result in the main engine being shut down. The failure mode with the highest risk level is pump impeller damage due to corrosion. As a solution, the study recommends predictive maintenance to anticipate impeller problems.

Yudo et al. (2026) is one of the studies closest to the current study because it directly applies RCM to the ship's main engine system. The study on the KM Lawit integrated FMEA, *Fault Tree Analysis* (FTA), *Reliability Block Diagram* (RBD), and *Monte Carlo simulation* . The FMEA produced the highest RPN for *the duplex fuel filter* at 288, *the lubricating oil filter* at 280, and *the expansion tank* at 140. The simulation results also showed a system availability level above 99%.

Wicaksana et al. (2026) analyzed the lubrication system of the main engine of the MV Meratus Borneo using RCM II and *cost-benefit analysis* . The results showed that *the lube oil pump* was a high-risk component and recommended *scheduled discard tasks* at 3,708.44-hour intervals. The study also showed that the strategy generated by RCM could be evaluated economically through *the benefit-cost ratio.*

TB Karya Pacific 2203 is a tugboat operating to support maritime transportation and service activities, namely by towing coal-laden barges. The high operational intensity of the vessel causes the main engine to work for a relatively long time, potentially experiencing various problems and component failures. Damage to the main engine can not only hamper ship operations but also has the potential to cause economic losses and risks to shipping safety. Therefore, a comprehensive analysis of the main engine maintenance system is required to identify critical components and determine a more optimal maintenance strategy.

Based on previous research, the FMEA method has been widely used to identify *failure modes* and determine risk priorities for ship engine components based on RPN values, while RCM is used to determine maintenance strategies based on function and consequences of failure. However, research that integrates both methods based on actual damage and maintenance data on tugboat main engines is still limited. Therefore, this study proposes the integration of FMEA and RCM on the TB Karya Pacific 2203 main engine. For this reason, this journal takes the title " **Maintenance Analysis of TB Karya Pacific 2203 Main Engine Using Failure Mode and Effects Analysis (FMEA) and Reliability Centered Maintenance (RCM) Methods ".** FMEA is used to identify *failure modes* , causes, impacts, and failure priority levels through RPN values, while the results are used as a basis in RCM analysis to determine appropriate maintenance strategies. The purpose of this study is to determine *the Risk Priority Number* (RPN) value based on *the Failure mode and effects analysis* (FMEA) method. as a basis for determining maintenance priorities, determining appropriate maintenance actions based on *the Reliability Centered Maintenance* (RCM) method , and can provide recommendations for effective maintenance strategies to improve the reliability of the TB Karya Pacific 2203 main engine . The contribution of this research is to produce a mapping of critical components and *maintenance task recommendations* that are adjusted to the actual conditions and operational characteristics of the TB Karya Pacific 2203 main engine.

METHOD

1. Types and Design of Research

study uses a quantitative descriptive method with a case study approach on the main engine of the TB Karya Pacific 2203 ship. The study aims to identify the types of main engine component failures, determine the risk priority level using *Failure Mode and Effects Analysis* (FMEA), and determine maintenance strategies using *Reliability Centered Maintenance* (RCM). FMEA is used to identify *failure modes* , causes, and impacts of failure and determine priorities based on *the Risk Priority Number* (RPN) value. Furthermore, the FMEA results are used as a basis in

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RCM analysis to determine maintenance actions that are appropriate to the function and consequences of component failure (Siahaan et al., 2025; Yudo et al., 2026).

2. Research Objects and Data

The object of this research is the main engine of TB Karya Pacific 2203, with a focus on components that play a crucial role in engine operation. The research data consists of primary and secondary data. Primary data were obtained through observations and interviews with the engine *crew* regarding engine condition, type of damage, cause of damage, impact of damage, and maintenance activities. Secondary data were obtained from *the engine log book, maintenance records, planned maintenance system* (PMS), repair reports, and engine manuals.

3. Data collection technique

Data collection is done through:

- Observation, namely direct observation of machine conditions and maintenance activities.
- Interviews, namely gathering information from *the chief engineer, second engineer,* and *engine crew* .
- Documentation, namely collecting historical data on damage, repairs and maintenance.
- Literature study, namely reviewing journals and references related to FMEA, RCM, and ship engine maintenance.

4. *Failure Mode and Effects Analysis* (FMEA) Analysis

FMEA is used to identify potential failure modes in main engine components. Each *failure mode* is assessed based on three parameters: *Severity (S), Occurrence (O), and Detection (D*).

The stages of FMEA analysis include:

1. Identify the main engine components.
2. Determine the failure *mode* .
3. Identify the causes of failure.
4. Analyze the impact of failure.
5. Determine *the Severity* (S) value.
6. Determine the *Occurrence value* (O).
7. Determine the *Detection value* (D).
8. Calculate *the Risk Priority Number* (RPN) value.

The Risk Priority Number (RPN) value is calculated using the equation:

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

Information:
S = severity of failure;
O = probability of failure;
D = level of failure detection capability.

Each parameter is assigned a value of 1–10, see Table 1. The higher the RPN value, the higher the priority of the failure to receive attention in maintenance activities. The FMEA approach with S, O, and D parameters has been used to determine the maintenance priority of components in the ship's engine system. Components with high RPN values are then selected as priority components for analysis using RCM (Siahaan et al., 2025).

Table 1. SOD Assessment

Mark	*Severity* (S)	*Occurrence* (O)	*Detection* (D)
1	No effect	Very rarely	Very easy to detect
2	Very light	Seldom	Easy
3	Light	Sometimes	It's quite easy
4	Currently	Quite often	Currently
5	Quite heavy	Often	It's a bit difficult
6	Heavy	More often	Difficult
7	Very heavy	Tall	Very difficult
8	Disrupting Operations	Very high	Almost undetectable
9	Nearly caused the engine to stall	Almost always	Undetectable
10	Machine failed to operate	Always	Impossible to detect

5. *Reliability Centered Maintenance* Analysis (RCM)

RCM is used to determine maintenance strategies based on component function and failure patterns. The analysis

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stages include:

- identify component functions;
- determine *functional failure* ;
- identify *failure mode* ;
- determine the effects and consequences of failure;
- determine appropriate maintenance actions.

The results of the RCM analysis are used to determine whether a component requires *preventive maintenance, condition-based maintenance, scheduled replacement, failure finding* , or *corrective maintenance* . The RCM approach has been used on the fuel, lubrication, and cooling systems of ship main engines to determine maintenance strategies based on critical components and the consequences of their failure (Yudo et al., 2026).

6. Data Analysis and Interpretation

FMEA data was analyzed based on RPN values to determine components with the highest risk priority. Next, these prioritized components were analyzed using RCM to determine the most appropriate maintenance strategy. The final results of the study included identification of critical components, failure types, RPN values, and recommended maintenance strategies that are expected to improve the reliability and operational readiness of the main engine.

RESULTS AND DISCUSSION

1. Ship Data

TB Karya Pacific 2203 is one of the fleets of ships owned by PT Karya Pacific Shipping which operates in Indonesian waters by towing loaded barges on deck. This ship was built in 2018, has an overall length (LoA) of 27.00 m, width (B) of 8.20 m, height (H) of 4.0 m, draft (T) of 3.30, gross rate tonnage (GRT) of 207 tons, main engine 2 units Yanmar 6EY-17W 1130 HP 1450 RPM, auxiliary engine 2 units Yanmar 4TNV106T-GGE 71 BHP.

2. Main Engine Maintenance System in Operation

Based on observations and interviews, the main engine maintenance system at TB Karya Pacific 2203 uses *a Planned Maintenance System (PMS).* This system schedules daily, weekly, and monthly inspections, as well as *overhauls,* based on the engine's operating hours.

Daily inspections include checking lubricating oil pressure, coolant temperature, fuel pressure, oil *level ,* coolant *level , and visual inspection for leaks throughout the engine system.* These inspections are performed by the engineer before the engine is operated and while the ship is sailing. Weekly maintenance includes cleaning the air *filter* , checking *the belt* , checking the condition of the *seawater cooling pump* , checking the fuel system for leaks, and tightening bolts on several components that experience high vibration. Monthly maintenance is carried out with a broader scope, such as replacing the fuel *filter , checking the injectors* , checking *the turbocharger* , changing the lubricating oil after reaching a certain operating hour, and checking the cooling system thoroughly.

Despite having a clear maintenance schedule, observations indicate that some maintenance work is still carried out after signs of damage appear. This is due to the ship's limited operational time, which is quite busy, so some components are still used until they are close to the failure limit. This condition indicates that the current maintenance system is still dominated by *preventive maintenance* combined with *corrective maintenance* . To improve the level of engine reliability, it is necessary to implement *Reliability-Centered Maintenance* (RCM), which considers the risk level of each component based on the results of *the Failure Mode and Effects Analysis* (FMEA).

3. Main Engine Component Observation Results

Based on the observation results, the TB Karya Pacific 2203 main engine is still able to operate well, however, several components were found to show a decrease in performance due to high operating hours. These main engine components are *the injector, fuel filter, seawater* cooling pump , turbocharger and oil pump. The decrease in performance is characterized by an increase in engine operating temperature, a decrease in lubricating oil pressure, a decrease in combustion quality, and the appearance of vibrations that are greater than normal conditions. The problems that occur do not always cause the engine to stop operating, but if not immediately addressed can develop into more serious damage. Therefore, identifying critical components is the first step in determining maintenance priorities.

According to Pramono et al. (2026), the use of turbochargers in marine diesel engines can increase output power and combustion efficiency, as well as reduce fuel consumption.

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Table 2. Identification of failures in main engine components

Number	Component	Disorders found	Impact
1	*Injector*	Dirty and clogged nozzle	Incomplete combustion
2	*Fuel filter*	Clogged filter	Reduced fuel flow
3	*Sea water* cooling pump	Seal is leaking	Increased engine temperature
4	*Turbocharger*	Carbon accumulation	Reduced air supply
5	Oil pump	Oil pressure decreases	Lubrication is not optimal

4. Discussion of FMEA analysis results

In a one year period, the problem of clogged *injectors* was recorded 7-8 times, the incident of clogged *fuel filters* was recorded 5-6 times, and *the mechanical seal* of the sea water cooling pump was leaked. occurred 3–4 times, carbon buildup on *the turbocharger* occurred 3–4 times, and oil pressure decreased due to oil pump gear wear occurred once. The results of the FMEA analysis on the TB Karya Pacific 2203 main engine can be summarized according to the table below.

Table 3. Results of FMEA analysis of TB Karya Pacific 2203 main engine

Component	*Failure Mode*	Reason	Impact	S	O	D	RPN	Priority
Injector	Clogged *Nozzle*	Carbon deposits	Incomplete combustion	8	7	4	224	Tall
Fuel filter	Clogged	Fuel impurities	Fuel supply is disrupted	7	6	4	168	Currently
Sea water cooling pump	*seal* leak	*mechanical seal* wear	*Overheating*	8	4	4	128	Currently
Turbocharger	Carbon buildup	Incomplete combustion	Turbo revs decrease	8	4	5	160	Currently
Oil pump	Oil pressure drops	Pump gear wear	Reduced lubrication	9	2	5	90	Low

The FMEA analysis results show that each component has a different level of failure risk. This difference is influenced by the severity of the damage's impact on engine operation, the frequency of failures, and the ship's *crew's ability* to detect damage early. The FMEA analysis results are used as the basis for determining maintenance action categories, consisting of *Time Directed (TD), Condition Directed (CD), Failure Finding (FF), and Run to Failure (RTF)* .

Based on Table 3, *injectors* have the highest RPN values, making them a component that should be prioritized in maintenance programs. A high RPN value indicates that *injector failure* has significant consequences for the main engine's combustion process. In addition to reducing combustion efficiency, *injector failure* also increases fuel consumption and accelerates the formation of carbon deposits in the combustion chamber and *turbocharger* .

5. Discussion of RCM analysis results

RCM analysis of the TB Karya Pacific 2203 main engine components based on observation data, interviews and literature reviews as well as from FMEA results, can be seen in table 5.

Table 4. Results of RCM analysis of TB Karya Pacific 2203 main engine components

Component	Function	*Functional Failure*	*Failure Mode*	*Failure Effect*	*Failure Consequence*
Injector	Atomizes the fuel so that combustion takes place perfectly	Fuel is not atomized properly	Clogged *nozzle*	Incomplete combustion	Loss of power, wasteful fuel consumption

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Fuel filter	Filters dirt before fuel goes to *the injector*	Fuel flow is obstructed	Clogged filter	Fuel supply is disrupted	The engine stutters to a stop
Sea water cooling pump	Circulate cooling water to the engine	Coolant flow decreases	*seal* leak	Increased engine temperature	*Overheating* , internal engine components warp
Turbocharger	Increase the combustion air supply so that engine power increases	Combustion air pressure decreases	Carbon buildup	Turbo revs decrease	Turbine performance is disrupted, engine power is reduced
Oil pump	Distributes lubricating oil to all moving components	Lubricant pressure decreases	*Gear* wear	Reduced lubrication, rough engine sound	Increased engine vibration

Based on the results of the FMEA and RCM analysis, the recommended maintenance strategy is as follows:

a. *Injector* : *The Condition Directed Maintenance strategy* was chosen because *the injector's condition* can be determined through physical inspection, spray pattern, *nozzle condition* , and combustion indications. This strategy is more appropriate than simply waiting for the injector to fail.
b. *Fuel filters* use a combination of *Time-Directed Maintenance* and *Condition-Directed Maintenance* . Filter replacement can be performed based on maintenance intervals, but the filter's condition must still be checked. If the filter becomes clogged before the replacement interval, replacement action must be performed earlier.
c. *Condition-Directed Maintenance for seawater* cooling pumps involves inspecting *the mechanical seal, impeller* , seawater flow, pressure, and engine temperature. The goal is to detect any decrease in cooling capacity before it causes *overheating* .
d. *Turbocharger Condition-Directed Maintenance* is performed by checking for carbon buildup, blade condition, and any indication of decreased performance. Cleaning is performed if *the turbocharger* shows signs of carbon buildup.
e. Oil pump: *Condition-Directed Maintenance* is performed by monitoring oil pressure and the condition of the pump gear. Any abnormal drop in oil pressure should be immediately followed up with a pump inspection.

CONCLUSION

Based on the description of the discussion and results of the FMEA and RCM analysis of the TB Karya Pacific 2203 main engine components above, the following conclusions can be drawn:

1. The main engine component with the highest *Risk Priority Number* (RPN) of 224 is *the injector.* This doesn't mean neglecting maintenance of other engine components, as there are hidden dangers that can cause fatal damage if the lubricant supply stops.
2. The recommended component maintenance strategy is *Condition Directed Maintenance* for *injectors, sea water* cooling pumps , turbochargers and pumps, *Condition Directed Maintenance* for *fuel filters.*

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