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FMEA Approach in Risk Analysis of Main Engine Fuel System Maintenance: Case Study on The Express Bahari 1F

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Abstract

The fuel system is one of the main engine support systems which is very important in the operation of the Express Bahari 1F main engine. Operation of the main engine requires special treatment of the components of the main engine to prevent failure during operation. The Failure Mode and Effect Analysis (FMEA) method is a method that can be used to identify the priority scale in maintaining a machine by evaluating the risk of failure occurring on the machine. This research uses FMEA analysis to determine the priority scale for maintenance of the Express Bahari 1F main engine fuel system. Data was collected by means of literature studies and interview surveys in the form of types of damage, failure mechanisms, effects of failure, how to detect failure, severity level, occurrence level and level of difficulty of detection as well as how maintenance was carried out. The identification results show that the injector, fuel filter and separator components are components that must be prioritized for maintenance. This type of maintenance is carried out by checking for dirty fuel which can cause the injector to operate less than optimally, cleaning deposits on the fuel filter cartridge on the fuel filter, and replacing a new separator if the separator performs poorly. It is recommended that other components be checked so that the main engine fuel system has good reliability.

Keywords: FMEA, fuel system, maintenance, main engine, RPN

1. Introduction

Indonesia is a maritime country that has a sea area of 5.9 km^2. Some of these areas are spread over many islands which of course require appropriate means of transportation, namely ferry vessels [1], [2]. The seaworthiness conditions of ferry vessels in Indonesia are often not paid attention to by their owners [3], [4], [5], [6], [7]. Inappropriate technical feasibility can cause the risk of accidents during operation [8], [9], [10]. Several technical feasibility of ship operations that need to be considered include the size of the ship, the ship's engine and the ship's crew [11]. Ship engines have a vital role on ships from a technical operational perspective because they act as a driving force for fishing vessels when operating. Many ship main engines use diesel engines.

A diesel engine or diesel motor is one of the engines used as a main engine. The use of diesel engines on main engines is because diesel engines have good durability and effectiveness when operated for long periods of time in crossing operations [12]. The performance of a diesel engine as a ship's main engine can function well if it is supported by a supporting system. The main engine supporting system consists of a fuel system, lubrication system, cooling system and starting system [13], [14], [15], [16], [17], [18]. The fuel system is one of the supporting systems for the main engine for the smooth operation of the ship's propulsion system. The fuel system has a role as a fuel supplier to the main engine from the storage tank to the main engine [1], [2], [12], [19], [20], [21], [22].

The main engine on the ship is operated 24 hours a day for 1 week to one month. Continuous engine operating conditions cause a decrease in engine performance. Continuous decline in engine performance can result in fatal main engine operating failures, such as incomplete combustion which causes the ship to stop operating at sea. Main engine failure that occurs while operating at sea can result in fatal problems for ships and ship members. Based on data published by PT. Indonesian Classification Bureau, the ships operating in Indonesia are between 21.1 years old . In general, the relationship between the age of the ship and the strength of the ship's construction is shown by a decrease in the ship's strength due to not receiving proper and regular maintenance.

Therefore, it is hoped that to continue to function well according to its intended purpose, it is necessary to carry out maintenance to maintain its strength by replacing components that experience decreased performance, treating corrosion protection, and other maintenance methods [23], [24], [25]. Special attention to the main machine when operating is the first step to prevent failure from occurring. Maintenance is an important activity to prevent damage to a machine. Main engine maintenance carried out by ship members can reduce the number of failures that occur [26]. The decision making process for main engine maintenance can improve the performance of the maintenance function.

Reliability Centered Maintenance (RCM) is a method for choosing maintenance priority decisions on blow mold machines in industry so that you can know which components need maintenance and reduce downtime on the machine. Machine maintenance strategies using the Maintenance Value Stream Map (MVSM) method can determine components that do not need to be maintained on Heavy Duty Hammer Shredder (HDS) machines. Another method for selecting machine maintenance priorities is the Analytic Hierarchy Process (AHP). The use of AHP in selecting machine maintenance strategies in the oil and gas industry can reduce maintenance costs and increase the readiness of machine components [27], [28], [29], [30], [31].

Failure Mode and Effect Analysis (FMEA) is a method of evaluating risks in the system [32], [33], [34]. FMEA can evaluate and analyze components in a system so that it can minimize the risk or effect of a failure rate as a supporting method for assessing performance in a system [35], [36]. The role of the FMEA method itself can be used to determine the risk of accidents in the system, the risk of component production failure, the risk of the supply chain system and so on. Research on maintenance analysis by detecting the risk of failure in machines or tools can be used with the FMEA method. The results can be obtained from three important components that must be prioritized in maintenance, namely the stick cylinder, fuel filter and oil pan. Another research that discusses machine maintenance analysis in an agro-industry uses the FMEA method. The results of previous studies found that the injector and fuel filter components needed more serious maintenance [37]. These results may differ from one ship to another.

Based on the explanation above, a method is needed to determine the selection or maintenance priority of fuel system components in the main engine. The aim of this research is to identify components in the main engine fuel system that have critical values based on FMEA calculations so that they can be prioritized for maintenance on the Express Bahari 1F Ship. This needs to be done so that maintenance activities can be carried out as optimally as possible so that shipping activities can run well.

2. Method

Making a risk-based maintenance analysis using the FMEA method has several steps that describe the identification and evaluation of systems, processes and maintenance to determine the maintenance strategy resulting from the method. Determining the object of this research is the fuel system of the main engine on the Express Bahari 1F. The main engine on the Motor Ship has the specifications shown in Table 1. The definition of the fuel system is based on the PID Block diagram obtained from the PID results of the installed components and adjusted to the manual PID drawing of the ship's main engine. Determination of process definitions and event studies for each component of the main engine fuel system are compiled from reference studies in articles that are matched with field data. Field data can be seen in the instrument data installed on the machine or the machine manual.

Data was collected by means of literature studies and interview surveys in the form of types of damage, failure mechanisms, effects of failure, how to detect failure, severity level, occurrence level and level of difficulty of detection as well as how maintenance was carried out. The survey process was carried out through unstructured interviews with the captain, head of the engine room or workers who had experience in ship main engines. This interview process is carried out by respondents answering questions on a standardized questionnaire on several pre-prepared scales.

Risk assessment using the FMEA method can use a qualitative value scale by identifying several predetermined criteria. This assessment can optimize maintenance plans for the ship's main engine. In this research, this method is used to identify parameters in FMEA, including:

a. The severity of the hazard is shown in severity (S). This section explains the seriousness of the dangers when the system is working (Table 1).
b. Frequency of occurrence shown in Occurrence (O). This section explains how many disturbances occur in components that cause the system to fail or can be called the opportunity for disturbances to occur (Table 2).
c. Detection level shown in Detection (D). This section explains how failures can be identified before/ just before the event occurs. Assessment is very subjective and depends on the experience of field sources (Table 3).

Risk Priority Number (RPN) is a combined result of three variables which include Severity (S), Occurrence (O), and Detection (D). To obtain this value, equation 1 is used [32], [33], [34], [35], [36].

$$RPN = S \times O \times D \tag{1}$$

The general structure of risk index parameters and the RPN matrix is used to collect data from the results of the assessment. The parameter structure of the risk index and RPN matrix can be shown in Table 4.

The RPN assessment is determined using a quantitative scale from the results of the interpretation of the qualitative scale. RPN provides information to determine the priority of potential failures in components. Determination of component maintenance priority is determined from the component RPN value that is above the overall RPN value threshold. The system RPN threshold value is obtained from the average RPN value for all components.

The flow chart of this research activity can be seen in Figure 1. From this picture it can be seen that the activity consists of data collection, data processing, and the analysis results obtained. These results are then used to determine what maintenance activities need to be carried out on the Express Bahari 1F.

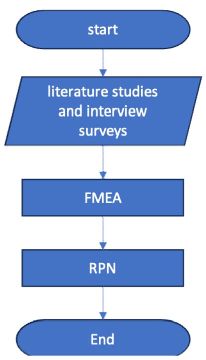

Figure 1. Flow chart of the FMEA on the main engine fuel system

Table 1. Failure severity level and danger level criteria

Danger level	Criteria	Value level
Very Dangerous	Component damage causes sudden accidents and endangers work safety	10
Very dangerous	Component damage causes work accidents and machines do not operate but there is early warning/detection	9
Very high	Component damage causes the machine to stop and lose its main function	8
High	Component failure results in the system shutting down but the machine still operating	7
Moderate	Component damage causes system performance to decrease drastically but the machine can still operate	6
Low	Component damage causes system performance to decrease gradually while the machine can still operate	5
Very low	Component damage results in little impact on system performance with the engine still operating perfectly	4
Small	Components experience decreased performance but the fuel system and engine are still running perfectly	3
Very small perfectly	Components are considered bad but component performance is still good and the system and machine are still running	2
Nothing	No influence	1

Table 2. Failure rate and number of events

Rate occurs	Number of events	Value level
Happens so often that damage cannot be avoided	Almost every time it occurs in less than 1-2 operations	10
Happens very often	Very high occurs in less than 3-4 operations	9
Happens very often (1)	High occurs in less than 5-8 operations	8
Happens very often (2)	High occurs in less than 9-20 operations	7
Rarely occurs (1)	Intermediate occurs in less than 21-80 operations	6
Rarely occurs (2)	Low occurs in less than 81-400 operations	5
Rarely occurs (3)	Rarely occurs in less than 401-2000 operations	4
Very rare (1)	Very rare in less than 2001-15000 operations	3
Very rare (2)	Almost never in more than 15001 operations	2
Never happen	Never happen	1

Table 3. Failure detection level and detection level criteria

Detection	Criteria	Value level
Impossible to detect	It will not be controlled and/or detected as potential causes of failure and subsequent damage	10
Very difficult to detect	It is very difficult to control changes to detect potential causes and subsequent types of failure	9
Difficult to detect	It is difficult to control changes to detect potential causes and subsequent types of failure	8
To be detected is very low	Very low to detect the cause potential and type of subsequent failure	7
To be detected low	Low to detect potential causes and types of subsequent failures	6
To detect medium	It is hardly easy to detect potential causes and subsequent types of failure	5
To be detected middle to upper	It is almost easy to detect potential causes and subsequent types of failure	4
Easy to detect	Easily controlled to detect potential causes and subsequent types of failure	3
Very easy to detect	It is easily controlled to detect potential causes and subsequent types of failure	2
Detection can be done easily/visible	It can be expected that their frequent occurrence will result in the detection of potential causes and events	1

Table 4. Matrix for filling in risk index and RPN parameters

Component	S	O	D	RPN
Fuel tank	X_{11}	X_{12}	X_{13}	RPN_1
Separators	X_{21}	X_{22}	X_{13}	RPN_2
Fuel distribution pump	X_{31}	X_{32}	X_{33}	RPN_3
Fuel filter	X_{41}	X_{42}	X_{43}	RPN_4
Injection pump	X_{51}	X_{52}	X_{53}	RPN_5
Injector	X_{61}	X_{62}	X_{63}	RPN_6

3. Results and Discussion

Based on the case study and field survey carried out on the Express Bahari 1F, it was found that the fuel system was in the main engine documents. Next, validate the fuel system in the engine room to ensure the components in the system match those installed in the main engine. Validation results and literature studies show that the Express Bahari 1F main engine fuel system has main components including Fuel Tank, Separator, Fuel Distribution Pump, Fuel Filter, Injection Pump and Injector Pump (Table 5).

The preparation of the Express Bahari 1F fuel system process is depicted using a block diagram in Figure 2. This block diagram image can be used as a reference as a system boundary for analyzing the risk of failure in the main engine fuel system using the FMEA method.

The results of the validation of literature studies and field surveys using the Failure Mode and Effect Analysis (FMEA) method for fuel systems are shown in Table 6. Based on the identification of the FMEA table, it explains the function of each component, the type of failure of each component, the mechanism of failure that occurs, the influence of the failure. on the system and main engine, how to detect failures and suggestions for reducing the occurrence of failures on each fuel system component. The results of the analysis of potential failures in the fuel system components form the basis for the RPN assessment.

Table 5. Express Bahari 1F Ship Specifications

Description	Specification
Machine	Caterpillar Inc
Machine code	C32
Machine type	4 stroke 24 cylinder
Fuel	Biodiesel
Cooling system	Closed system
Power	1450 HP
RPM	2100-2300 RPM
Year of engine build	2014

The results of the FMEA approach provide information on the possibility of failure of each fuel system component along with identical RPN values obtained from these results (Table 7). In general, it can be assumed that all risk index parameters have an equal role in prioritization.

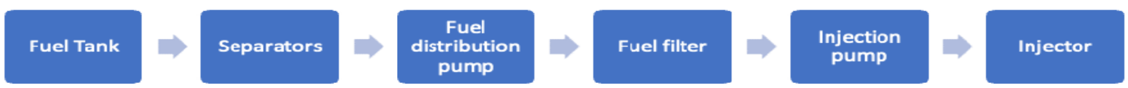

Figure 2. Express Bahari 1F main engine fuel system block diagram

Table 6. FMEA analysis of the Express Bahari 1F fuel system

Component	Function	Failure Mode	Failure Mechanism	Effect Failure	Risk Reducing Measure
Fuel tank	Fuel storage area	Leaks in the fuel tank wall	Corrosion	Explosions in tanks and pollution of the sea and its ecosystem	Tank coating periodically
Separators	Separating fuel particles from water and solid content	Dirty and contains water sediment	Dirty fuel	The combustion process in the main engine decreases	Cleaning the separator periodically
Fuel distribution pump	Transfers fuel from the tank to the pump to the ignition chamber	Decrease in fuel flow pressure	The seal on the pump is damaged	Decreased engine performance	Checking and replacing pump seals periodically
Fuel filter	Separating fuel from fine particles	Clogged and dirty fuel	Dirty and deposits occur	Decreased engine performance and engine shutdown	Cleaning and replacing filters regularly
Injection pump	Converting fuel pressure into high pressure to be delivered to the injector	Low fuel flow pressure	Pump component fatigue	Decreased engine performance and engine shutdown	Checking periodically
Injector	Spraying fuel in the ignition chamber of the main engine	Clogged	Dirty on fuel	incomplete combustion and the engine shutdown	Checking periodically

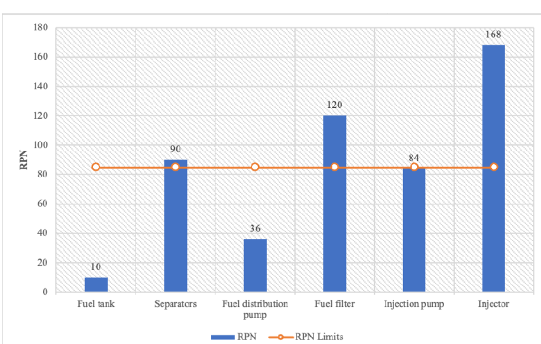

Figure 3. Priority diagram for handling component damage

Figure 4. Injector components

Figure 5. Fuel filter components

Figure 6. Separator components

The image shows the RPN value for each component in the Express Bahari main engine fuel system. The results of the calculation show that the injector component has the highest value in the RPN calculation, namely 168. The results of the injector RPN calculation with a Severity value of 6 states that if a failure occurs, system performance will decrease, an occurrence value of 4 states that a failure mode occurs after the system operates less than 401-2000 times of operation. A detection value of 8 indicates the level of difficulty in detecting and controlling if a failure occurs in the component. The RPN value of the injector component is very different from the value obtained by the fuel filter component. Based on previous research, the fuel component is one of the components that needs to be maintained because it has the highest failure rate. The injector component has a high RPN value because it has a higher occurrence rate and detection rate than other components. Even though the injector has a low severity level, the RPN value of the injector component is still the highest. This confirms in theory that the RPN value is very dependent on three parameters, namely severity, occurrence and detection. The risk level gets higher depending on the RPN value obtained so that the RPN value is closely related to strategy selection. Based on Table 7 and Figure 3, the RPN value of each failure mode for the fuel system components has a range of 10 to 168.

Table 7. Values of risk index parameters and RPN matrix

Component	S	O	D	RPN
Fuel tank	5	1	2	10
Separators	5	6	3	90
Fuel distribution pump	4	3	3	36
Fuel filter	6	4	5	120
Injection pump	6	2	7	84
Injector	6	4	7	168

Based on Figure 3, there are RPN threshold values that have been calculated for all components of the main engine fuel system. The RPN threshold value is 84.67. The RPN threshold value becomes a reference benchmark for priority for components by creating categories of RPN value for components that exceed this threshold. This average value is the limit for carrying out preventive and maintenance actions on these components. Based on Figure 3, the injector (Figure 4), fuel filters (Figure 5) and separators (Figure 6) are components that have priority maintenance in the main engine fuel system.

An alternative step in operating the main engine is for the head of the engine room to always reserve several ship components. The injector component itself plays a vital role in the operation of the main engine. If there is damage to the injector, engine performance will decrease and the ship will not work optimally because the engine's propulsion power is not optimal. Mitigation steps that can be taken are to check the injector components when they are about to operate. Apart from the injector components, special attention must also be given to the fuel filter components in maintaining the main engine fuel system because the RPN value also exceeds the threshold. The fuel filter component itself failed, namely becoming clogged due to solid particle deposits. Even though the fuel has been separated through a separator first, fine particles can pass through the separator process so that the filter is often dirty, causing the filter to become clogged. Several maintenance periods before operating the fuel filter components are something that must be considered. The maintenance carried out on the filter is to clean the sediment around the filter walls. Apart from that, if you feel that the condition of the filter is no longer suitable, you can use a spare which is always carried by the Head of the Engineering Room. The maintenance carried out on the separator is to replace it with a new separator. If the separator's performance is poor, this can be done from the main machine panel. This maintenance is carried out once a month. Mitigation actions that need to be taken include routine inspections and special maintenance for components that have an RPN above the threshold.

4. Conclusion

Based on the discussion above, maintenance must be carried out on the fuel system components of the Express Bahari 1F main engine, namely the injector fuel filter and separators. These components are prioritized because they exceed the critical limit of the fuel system RPN and are included in the components that must be prioritized. Maintenance measures for injector components include routine checks before operation and special maintenance by paying attention to the purity of the fuel entering the main engine fuel system. Meanwhile, the maintenance action for the fuel filter components is routine cleaning of solid particles. The maintenance carried out on the separator is to replace it with a new separator. If the separator's performance is poor, this can be done from the main machine panel. Maintenance actions on critical components can reduce the risk of failure in the main engine fuel system.

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