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Failure Analysis of Fuel System Main Engine Fishing Vessel (Case Study : KM. Sumber Mutiara)

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Article Info

Abstract

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Failure analysis on the fishing vessel's main engine is one of the works that must be completed because it is crucial for the operation of the ship. Analysis of determining the cause and effect of the failure main engine fuel system is the goal of this study. FMEA (Failure Mode and Effect Analysis) is a method used to determine priority components in failure. The use of Pareto diagrams is an additional method of analysis. RCFA (Root Cause Failure Analysis) is used to analyze the root cause of the failure of the main engine fuel system. The results obtained are the injector component (168) is the component that has the highest RPN (Risk Priority Number) value and is the largest contributor to failure according to the Pareto diagram. The root of the failure has been identified, namely the lack of checking before operating. The Obtained results of the recommendations are the use of corrective maintenance based on the RPN value and the use of a clean filter for the fuel system. The injector is a component that needs to be maintained so as not to experience a fuel system failure on the main engine. The contribution of this study has been to confirm a scientific finding using FMEA and RCFA as a method of analyzing failures in the main engine fuel system on fishing vessels

1. Introduction

The main engine is one of the important engines on fishing vessels, because the main engine is the propulsion of the ship when operating. Diesel engines are commonly used as the main engine on fishing vessels. The diesel engine is used as the main engine because the diesel engine is more effective and efficient in its long operation [1]. Diesel engines have more economical fuel consumption and can get more power than gasoline engines when operating [2]. A diesel engine is a machine that can produce mechanical power through a fuel combustion system. Diesel engines in operation require a support system [3]. Support systems on the main engine include the fuel system (fuel oil system), lubrication system (lubricating system), cooling system (cooling system) and the start system (starting system) [4][5]. The fuel system is one of the most important support systems. This is due to the fuel system as a fuel supplier from the fuel tank to the combustion chamber so that the diesel engine can operate [6].

The main engine of fishing vessels in the shipping process operates 24 hours a day for a week to a month [7]. continuous operation causes some components of the main engine to experience a decrease in quality until the failure of the main engine components. Failure to occur in one component of the main engine causes damage to all components of the main engine that are operating and result in large losses and high risk [8]. Several incidents caused by engine failure are ship accidents. Its ship accidents are caused by several factors, including human factors and machine complexity. Several incidents of main engine failure that resulted in ship accidents, among others, the MV Bright Field incident in 1996 and MV. Planets in 2012 [9]. Based on this experience, it is necessary to analyze several failures, especially on important components and need to be considered in ship operations.

Several studies have been conducted using several methods to detect system failures. One of all is Windyandari [10] the use of important diagnostic techniques in determining the causes and consequences of engine failure is an important point in finding engine failure problems. Methods that can be used to find the cause and effect of system or machine failure are FMEA (Failure Mode and Effect Analysis) and RCFA (Root Cause Failure Analysis). Research by Anthony et al [11] uses FMEA in analyzing damage to the Hot Roller engine. The results find out the cause by using the Paretto diagram as a result of the RPN (Risk Priority Number) per component. Another study discusses the analysis of fuel pump failure in diesel engines using the FMEA method. The result is that the cam plate component has a high RPN value so that it is identified as the cause of failure [12]. Furthermore, the failure in the diesel engine is analyzed using the highest RPN value. The result is the piston as the cause of damage to the cylinder block so that the diesel engine fault [13]. In addition to failures in the engine, the study of Li et al. [14] analyzed failures in wind turbines which were divided into three categories using the FMEA method. As a result, the mooring system becomes a component that is identified as the cause of failure. On the other hand, the use of RCFA can analyze the cause and effect of failure in processes and systems in more detail. One of the studies conducted by Masriera et al, [15] used the RCFA method in analyzing failures, which included an Ishikawa diagram to look for variables that caused the start bar to break. The use of the Ishikawa diagram in the RCFA method can analyze the failure of the 500kV reactor generator system caused by reactor vibration [16]. In addition, the use of the Ishikawa diagram in the RCFA method can analyze the failure of the muffler mounting bracket caused by the material [17]. Currently, RCFA can be used in analyzing the causes of damage and repairing auxiliary machines, namely conveyors, making it easier for the repair process [18].

Several methods are commonly used in analyzing machine failures. However, these methods must be mutually reinforcing in order to become a sharper analysis. The use of the combined FMEA and RCFA methods in analyzing the main engine failure is still widely used. The use of FMEA and RCFA combined analytical methods and techniques is a new thing in analyzing. Based on the discussion that has been described, the purpose of this article is to determine and analyze the cause and effect of the main engine fuel system component that failure. Determination of cause and effect cannot be separated from calculations on FMEA, Pareto diagrams and Fishbone diagrams. The contribution from the study of failure analysis using the FMEA and RCFA methods produced can be scientific findings in the field of ship engine system failure, especially fishing vessels. The application of the new method can make it easier to find and document the findings of failure in a system or machine.

2. Methods

2.1. Data Collection

Determination of the object of research is carried out on fishing vessels located in Batam City, Riau Islands, Indonesia. A fishing vessel with a purse seine GT182 and a 500PK engine with the Cummins. The main engine component data was obtained from the P&ID (Piping & Instrumentation Diagram) of the engine manual and validated by field observations on the engine. Determination of the process flow definition per component in the system in the main engine is based on literature studies, interviews and observations so that they can be presented in block diagrams. The collection of damage data, failure mechanism, failure effect, failure detection, severity, occurrence rate and detection rate were obtained from a combination of literature studies with interviews with several crew members. The interview process was carried out on the ship's crew who experienced cases because the ship's crew better understood the process and treatment of the machines used. The interview process was conducted with three experts, including the Captain, Head of the Machinery Room or workers who have more than 5 years experience. The selection of three experts who were interviewed was due to the fact that fishing boats are the object of research, the work of ship engines is more carried out by these experts. While the rest of the ship members are more focused on catching fish. The standardization and consistency of expert interview evaluation is carried out with the guidelines shown in Table 1. The process of data collection activities is shown in the flow chart of Figure 1.

Table 1. Indexed parameter (S, O, and D) rankings for RPN estimation

Effect	Severity Level (S)	Probability of Occurrence (O)	Detection Criteria (D)	Rating/ Scale
Hazardous	When the effect of potential failure mode without notification	Very high: failure is almost unavoidable (1-2 times in operation)	Controls actions are not available (Not possible)	10
Very high	When a potential failure mode effect	Very high: failure is almost unavoidable (3-4 times in operation)	Extremely low possibility of noticing the breakdown (Very remote)	9
High	System inoperable due to destructive failure	High: repeated failure, A process that has often failed (5-8 times in operation)	Low possibility of noticing the breakdown (Remote)	8
Moderately High	System inoperable due to harsh failure	High: repeated failure, A process that has often failed (9-20 times in operation)	Low possibility of noticing the reasons for the occurrence of breakdown (Low)	7
Moderately Low	System inoperable with minor or notable failure	Moderate: infrequent failures with little impact (21-80 times in operation)	Low chance of detecting a possible cause and consequent failure mode (Low)	6
Low	System inoperable with minor or prominent failure	Moderate: infrequent failures with little impact (81-400 times in operation)	Reasonable possibility of noticing the reasons for the occurrence of breakdown (Moderate)	5
Very Low	System operable with few failures	Low: relatively few failures are associated with similar processes (401-2000 times in operation)	Reasonably high possibility of noticing the possible reasons for occurrence of breakdown (Moderately high)	4
Very Remote	System operable with relatively few failures	Low: relatively few failures are associated with similar processes (2001-15000 times in operation)	High probability to notice the potential reasons for the occurrence of breakdown (High)	3
Remote	No effect but there is a suspicion of failure	Remote: failure is almost implausible (More 15001 times in operation)	Very high probability of noticing the potential reasons for occurrence of breakdown (Very high)	2
None	No effect	failure is impossible	Required controls are available to detect a failure mode (Assured controls)	1

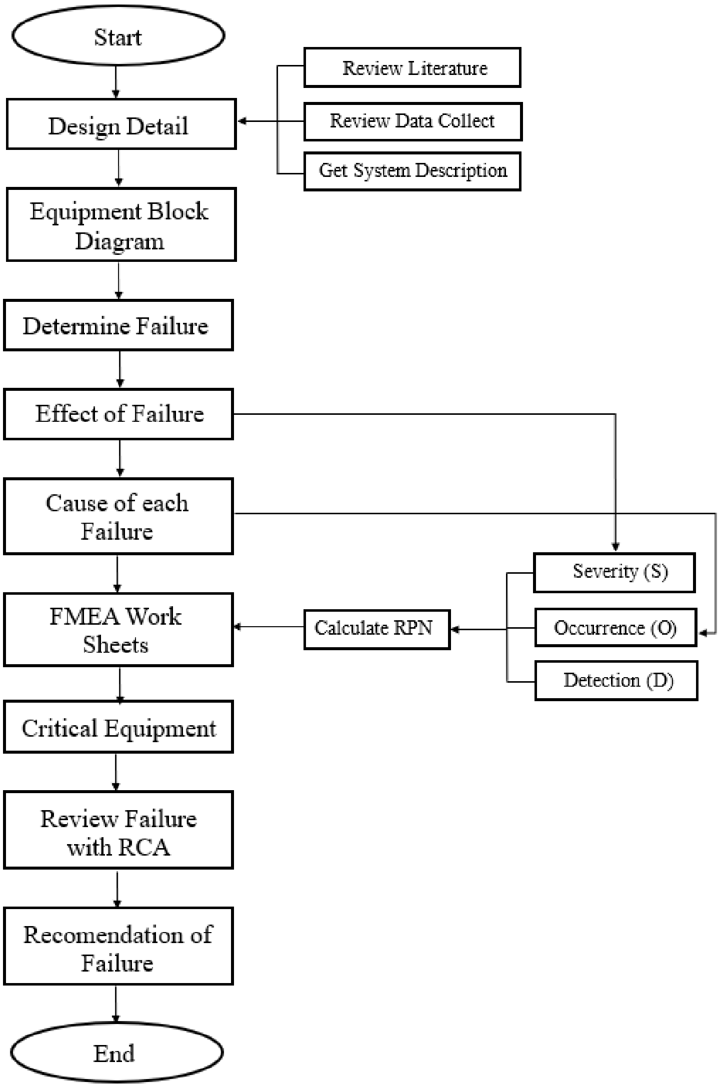

Figure 1. Flow Chart for the Failure analysis fuel system main engine

2.2. FMEA Method

Failure Modes and Effects Analysis (FMEA) is a systematic technique for identifying, analyzing, and preventing system and process problems. FMEA begins with the identified fuel system components. The relationship between the machine and its working environment needs to be clearly observed in order to determine the effects and reasons for the failure. The steps for implementing FMEA in this study are as follows:

i. Categorize components of the main engine fuel system by type of failure
ii. Function analysis of the components of the block diagram that has been obtained. Each function category and function must be specified.
iii. Identify the failure mode for each component. Each failure needs to detail the effect of the failure and how often it occurs.
iv. Record some effects, mechanisms, effects and failure detection on the FMEA worksheet.
v. Calculation of the RPN (Risk Priority Number) value from the Severity (S), Occurrence (O) and Detection (D) parameters. The highest RPN value is the alleged damage to the main engine's fuel system
vi. Implementation of the results of the FMEA analysis.

This study uses FMEA as a failure identification based on the highest RPN value, but it is also necessary to pay attention to the failure mode of each component. In general, component failure parameters can be determined by calculating the RPN value. The RPN value is obtained from the calculation results of 3 parameters Severity (S), Occurrence (O) and Detection (D) which are in accordance with Equation 1 and Table 1 [19], [20]:

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

i. Severity (S)
The seriousness and criticality of the impact of the hazard. The score obtained from the assessment of the impact of the hazard caused by the failure effect.
ii. Occurrence (O)
The estimated number of potential failures in a system. The assessment is obtained from the probability evaluation of the effects that occur as a result of the failure mode.

iii. Detection (D)

Possible defects can be identified to work procedures. Assessment based on capacity to recognize the mode of damage that occurs.

Table 2. General structure of matrix RPN

Equipment	Severity	Occurrence	Detection	RPN
EF_1	X_{11}	X_{12}	X_{13}	RPN_1
EF_2	X_{21}	X_{22}	X_{23}	RPN_2
EF_3	X_{31}	X_{32}	X_{33}	RPN_3
.	.	.	.	.
.	.	.	.	.
EF_7	X_{71}	X_{72}	X_{73}	RPN_6

The obtained RPN is evaluated using Table 2 based on Equation 1. RPN data processing uses Pareto diagrams. Pareto diagram is a histogram diagram that can analyze critical areas/components. Determination of critical components identified from 20% is the type of failure of 80% of the entire system. It can be said; Pareto diagram is used to determine the critical point. The next data processing after the cause of component failure is found is to determine the maintenance strategy for each component. The component maintenance strategy is based on the obtained RPN value. The RPN values obtained are classified in Table 3 [21][22].

Table 3. Strategic maintenance criteria

Rank	Strategic Maintenance	Criteria
1	Predictive Maintenance	RPN > 300
2	Preventive Maintenance	200<RPN<300
3	Corrective Maintenance	RPN <200

2.3. RCFA Method

Root Cause and Failure Analysis (RCFA) is one method that is often used to identify the main possible causes of failure in systems or machine components. The cause of failure does not depend on a single cause, but several factors that cause failure. This study uses a fishbone diagram to analyze. A fishbone diagram is a detailed way to list all possible causes of failure and their causes. Therefore, fishbone diagrams are also called cause-and-effect diagrams. This helps designers and process planners to pay attention to future failures. Fishbone diagrams use several factors, namely man, material, method and machine in considering the failure. Each factor will be related to other factors. Each of the causes listed are identified to determine the main cause of failure based on the results of field observations.

3. Results and Discussion

3.1. Case studies and Block diagrams of fuel system main engine components

This article presents a case study where the analysis of the root causes of failure in the main engine of fishing vessels, especially in the fuel system. The fishing vessel used as the research object is KM. Sumber Mutiara. KM. Sumber Mutiara is a fishing vessel operating in Natuna Sea Waters, Indonesia with Purse Seine fishing gear. KM. Sumber Mutiara was made in 2002 with a 500PK main engine (Cummins, KTA19). These fishing boats run from the port to the fishing area. The fuel system failure occurred in May 2022. The process of the main engine failure when the ship sailed to the port, occurred still in Indonesian Sea waters. The ship has a problem with its propulsion system when the ship is running. After that, the ship's crew checked the ship's propulsion system, especially on the ship's main engine. The main engine has symptoms that have been signaled by abnormal combustion parts. Generally, incomplete combustion performance with the influence of the fuel or its environment on the engine combustion chamber is called knocking-combustion [23]. Where the crew of the ship felt an abnormal engine in the main engine fuel system section. Then do a small check and make sure the location of the failure. The results of the check suspected that the engine had failed in the fuel system. After arriving at the port, the engine was evaluated and confirmed to have experienced a failure in the fuel system. Based on the history of repairs, the main engine on fishing vessel is often failure, especially in the fuel supply section. Because the same failure often occurs to the main engine fuel system, ship management companies often provide repair services and spare parts for the main engine to keep the ship sailing. Although some systems also need attention, the fuel system is the first priority in solving problems in the main engine. However, maintenance of the main engine on board needs to be improved because the factor can extend the life of an old engine. Therefore, when one of the components is damaged, the cause and effect of the failure can be identified and improvements are recommended so that it does not happen again. Wang's study [24] states that the fuel system in diesel engines generally needs attention because failures often occur.

One of the most important parts of applying the FMEA method is breaking the system into its own components. The main advantage of dividing the system into individual components is to more easily identify failure modes, causes and effects on the system [19]. The fishing vessel's main engine consists of various main engine support systems. One of the most important is the fuel system. Based on the results of PI&D observations and interviews and validated by literature studies, the components of the fuel system are fuel tank, fuel pump, filter, injector pump and injector. This block diagram is a reference in analyzing failures that occur in the fuel system of the fishing vessel's main engine [7]. The main engine fuel system block diagram is shown in Figure 2. The process flow diagram can be explained based on the use in Table 4. Thus, the main engine fuel system equipment block diagram shows the interacting parts to verify the fuel distribution.

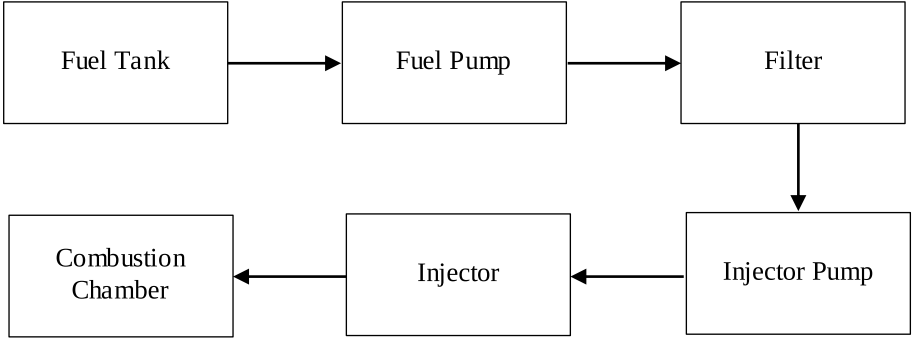

Figure 2. Block diagram of fuel system main engine

After dividing the components in the main engine fuel system into several pieces of equipment, identifying the failure mode and the impact of each equipment failure is important. In general, failure of fuel system equipment can occur from various aspects. Likewise, with the mechanism of failure. The results of interviews from experts along with literature studies can be used as a result of identifying failure modes and their mechanisms and impacts and how to identify them. Some of these failure modes are written on the FMEA worksheet which is shown in Table 4. The results from Table 4 are taken into consideration from the results of the RPN [25].

Table 4. Failure mode and effect analysis of fuel system main engine

Equipment	**Function**	**Potential Failure Mode**	**Reason for Potential Failure Mode**	**Effect of Potential Failure Mode**	**Detection of Potential Failure Mode**
Fuel Tank	Storage area for fuel before it is supplied to the main engine	Leaks in the walls (F_1)	Corrosion on walls	Big explosion and sea water pollution	Visual Observation or Non Destructive Test
Fuel Pump	Transferring fuel to the main engine	Blockage of the intake and/or exhaust ducts (F_2)	Dirt particles settle	The machine is not working optimally	Pressure gauge check and overhaul
Filter	Filter fuel before supply to main engine	Dirty and clogged fuel filter element (F_3)	Dirty deposits occur	Decrease in engine performance until the engine dies completely	Overhaul of the machine
Injector Pump	Increase the fuel pressure to the injector	Fuel flow pressure changes (F_4)	Component fatigue	The engine does not work optimally until the engine dies	Overhaul and checking with pressure gauge
Injector	Spraying fuel with the atomization method on the main engine fuel	Clogged fogging (F_5)	Small particles clog	Combustion is not perfect so the engine is not optimal	Overhaul and checking with the injector tester

3.2. FMEA analysis

Investigate the main engine fuel system to analyze failures. Details of past failures in the fuel system are obtained and analyzed according to the history of the fuel system components. Based on the type of failure per component, system failure is classified into 5 parts, namely Fuel Tank failure (F_1), Fuel Pump failure (F_2), Filter failure (F_3), Injection Pump failure (F_4) and Injector failure (F_5) [7]. All functions and types of failure of the fuel system components are investigated in Table 4. The failure of this component is observed so that it can predict the probability of failure by identifying the history of failure. Based on the function and failure of its function, a description of the mechanics, causes and methods of identification is obtained to serve as a basis for assessment. The type of failure obtained was assessed with parameters S, O and D based on the contents of Table 4. The RPN value obtained from the S, O and D mathematical calculations shown in Table 5 while still considering the severity value [12]. The RPN value is validated with field data so that the obtained RPN value can be validated [26]. Based on the obtained RPN, the highest value of RPN is in the injector component (168). The RPN value of 168 is obtained from parameter S with a value of 7, parameter O with a value of 4, and parameter D with a value of 6. The parameter value S states that the injector component if it fails will cause the engine to die with the injector being very dirty and clogged with fuel into the chamber. engine combustion. The parameter value O indicates that the injector component is not frequently maintained with a low probability of occurrence of the main engine fuel system failure. The parameter value D indicates that the injector component has a low chance of failure identification because it is located inside the engine. So that some of the detection of this component is done by analyzing its impact. One of the impacts is the vibration caused [27]. The results of the RPN calculations in Table 5 which are affected by S, O, and D can be shown in Figure 3 and then the RPN values obtained are analyzed.

Table 5. Indexed RPN calculation result value

No	Component	Severity (S)	Occurrence (O)	Detection (D)	RPN
1	Fuel Tank	8	2	4	64
2	Fuel Pump	5	3	5	75
3	Filter	7	3	5	105
4	Injector Pump	6	2	6	72
5	Injector	7	4	6	168

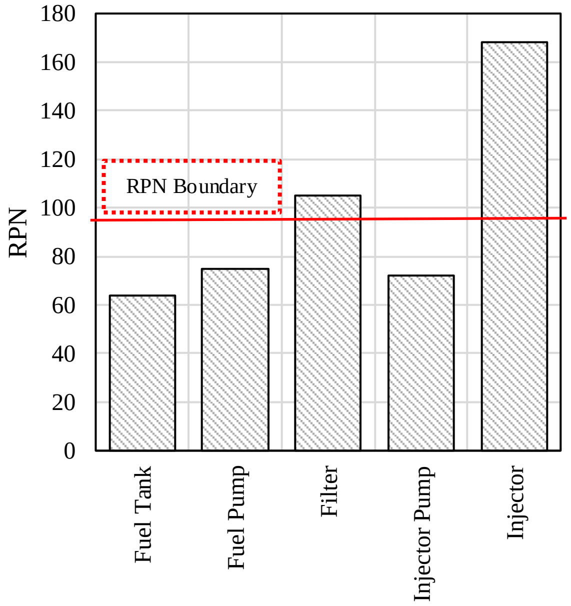

Figure 3. Component failure priority diagram from RPN

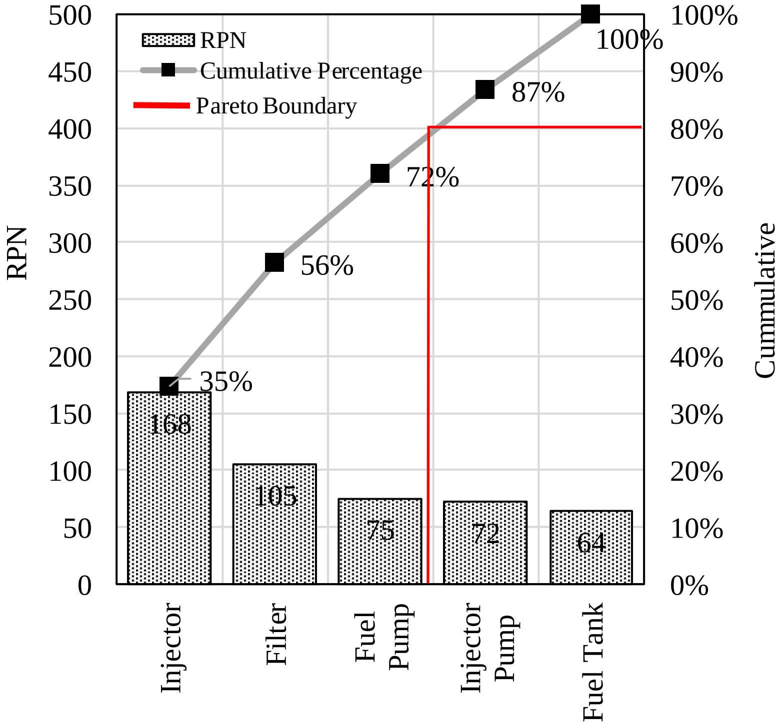

Figure 4. Pareto diagram of RPN fuel system main engine component

The calculation of the RPN value is used to analyze the critical components that cause the failure of the fuel system. One of them is by investigating the results of the selection of components that exceed the critical RPN limit of all components. The Critical RPN (96.8) is obtained from the average of all RPN values on the main engine fuel system components [28]–[30]. Figure 3 shows the main engine fuel system components with the RPN value limit. Based on Figure 3 shows the filter and injector components are components that exceed the RPN limit value. This is reinforced by Figure 4 which shows the results of the Pareto diagram analysis of the RPN value of the fuel system. Based on the Pareto diagram, the most dominant component of failure is the injector component. However, it is not possible for failure to occur due to the filter or fuel pump. In accordance with the Pareto principle which states 80/20 where 80% of failure problems are caused by 20% of the causes of failure [31]. The results of field investigations and several analyses, the components that cause fuel system failure are in the injector component that exceeds the RPN limit with the highest RPN value and the largest percentage of contributors to failure on the Pareto diagram.

3.3. RCFA analysis

The potential causes of failure in the main engine fuel system have been identified. The main component of the main engine fuel system failure is the injector. The results of the injector analysis have the type of failure that is clogged at the nozzle. Figure 5 shows an image of a clogged nozzle point. The failure of the injector component needs to be investigated again for its causes. The potential for failure of the injector is identified and categorized as causes and effects related to failure are material, machine, human and method [32][33]. Figure 6 shows the ishikawa diagram (fishbone diagram) of injector failure. Each category includes several causes related to a particular category and is further broken down into other sublevels to more deeply find the root cause. Based on brain stroming and analysis with Ishikawa diagrams, there are 10 root causes. Based on the root of the problem, the lack of regular maintenance which causes checks not optimal when the machine is working is the root of the problem. After determining the problem, it is further evaluated with experts and field conditions.

The cause of the problem is often the lack of periodic checks resulting in damaged injectors. Some of the injector failures are clogged injectors due to inappropriate injector settings. Blockage of the nozzle on the injector can cause incomplete fuel spraying in the combustion chamber. This causes the machine to fail [34].

Figure 5. Injector nozzle

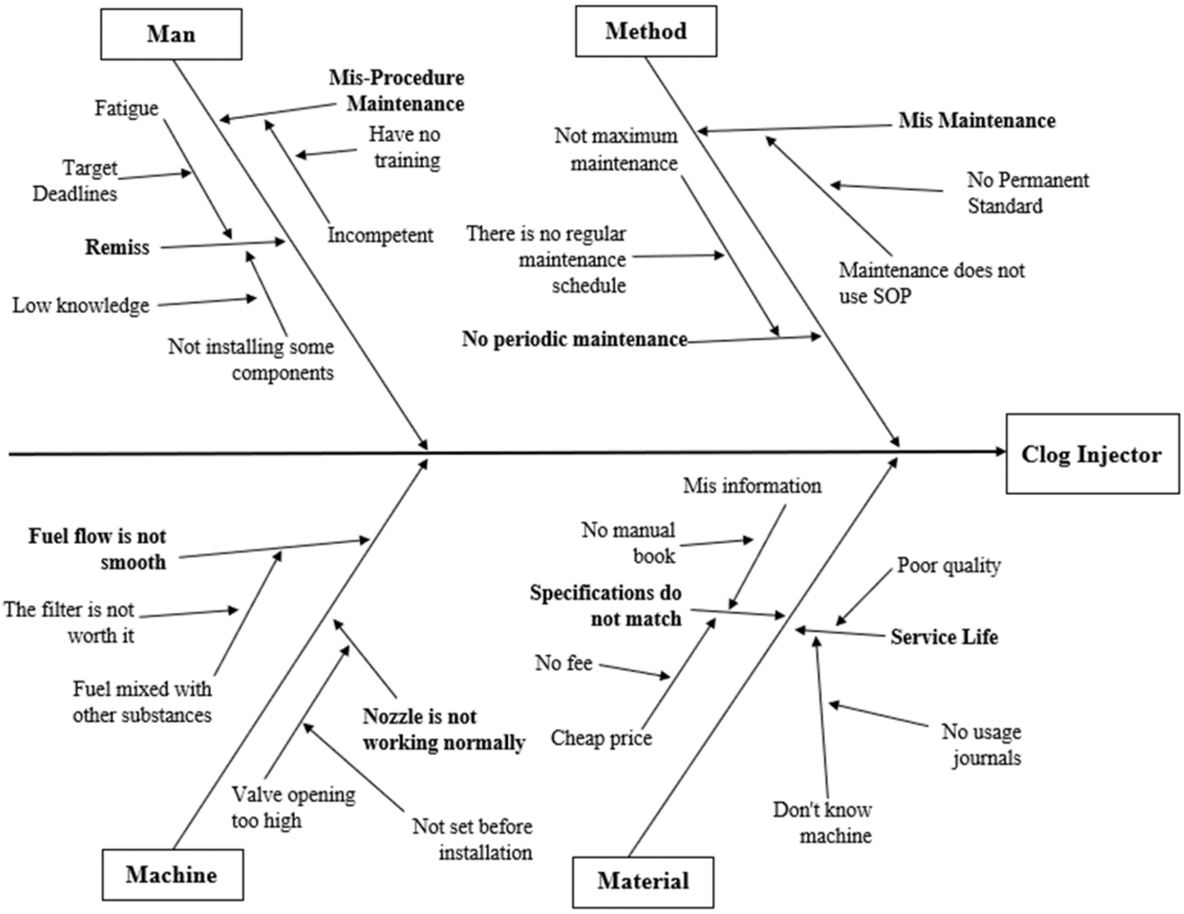

Figure 6. Root case failure analysis using Ishikawa diagram

3.4. Recommendation

The causes of the main engine fuel system failure which resulted in the main engine shutting down was the failure of the injectors. However, the failure of the injector causes the combustion to not occur in the combustion chamber. The results of the analysis above the cause of the failure of the injector is the blockage of the nozzle. The root cause of injector failure is the lack of component checks before operation. Procedural treatment is a traditional but effective action. The treatment selection strategy is determined by the RPN value. The classification of treatment strategies based on RPN values is shown in Figure 7. The injector component (168) is recommended to use corrective maintenance [35]. Another suggestion is that periodic checking before the machine operates is one of the techniques to avoid failure. The use of a clean fuel filter also reduces the causes of failure.

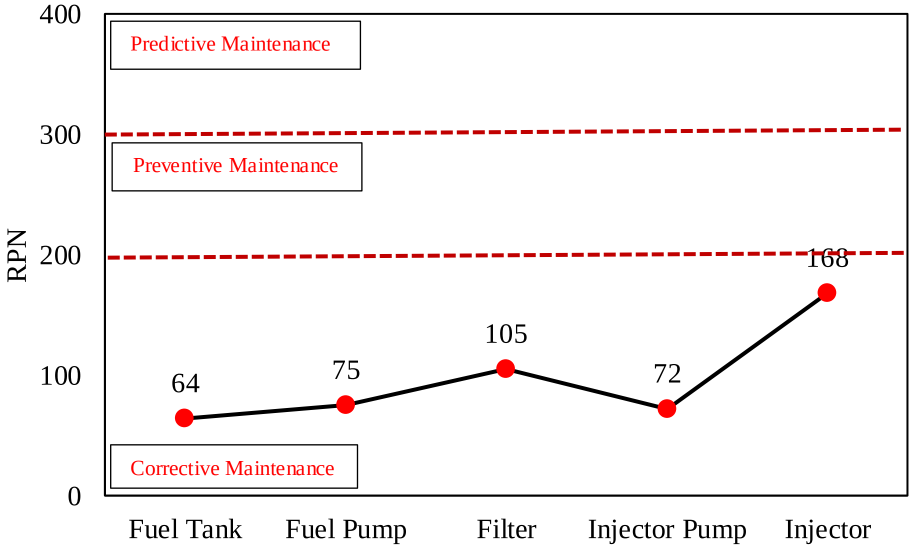

Figure 7. Strategic maintenance of injector failure

4. Conclusion

This study was designed to analyze the cause and effect of the main engine fuel system components that have failed. The RPN results of the various components of the Fuel Tank, Fuel Pump, Filter, Injector Pump and Injector were 64, 75, 105, 72 and 168 respectively. Investigations in the FMEA analysis found that the injector component was the cause of failure with a large RPN value of 168 and as the biggest cause of failure based on the Pareto chart. Failure that occurs is a clogged injector. The RCFA results show that the root cause of injector failure is inadequate checking. Therefore, a corrective maintenance strategy is the right step in mitigating it because the RPN value is <200. In addition, cleaning the filter components regularly can also minimize failures. The impact of this research is scientific findings that can have an impact on failure analysis using the FMEA and RCFA methods.

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