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RELIABILITY-BASED PREDICTABLE MAINTENANCE OF THE 2800 GT CONTAINER SHIP FUEL SYSTEM

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ABSTRACT

The fuel system is a supporting system for the ship's main engine because this system directly affects the performance of the main engine. The fuel system is so important that it will have a direct impact on the performance of the main engine and affect the ship's operations. To prevent danger or loss resulting from fuel system failure, a reliability-based maintenance analysis is needed. This research will analyze failures and create a maintenance schedule for the fuel system on the ship's main engine. In completing this research, a qualitative method was used, namely using Fault Tree Analysis (FTA) and Failure Mode and Effects Analysis (FMEA. Then, quantitative analysis was carried out using the Weibull distribution to determine the mean time to failure (MTTF). The results of the research showed that the predicted maintenance of the main engine fuel system was correct based on the reliability value calculation. The reliability value of the Transfer Pump component was 5950 hours with a reliability of 0.66, the Booster Pump 4325 hours with a reliability of 0.749, the Purifier 5530 hours with a reliability of 0.66, the Injector 2010 hours with 0.93 reliability, and the Filter 967 hours with 0.86 reliability.

Keywords: Failure mode and effect analysis, fault tree analysis, ship's fuel system, reliability, weibull distribution

Introduction

Indonesia is an archipelagic country. Indonesian waters are strategic shipping lanes where sea transportation is one of the port transportation systems that plays a strategic role. Ships are vehicles that carry passengers at sea, in all areas that have certain waters [1]. A ship that functions as a means of transportation, or in other words, a ship functions to move passengers and goods [2].

Maintenance of a ship is something that cannot be ignored because if it is not carried out on an ongoing basis, there will be a decrease in the performance of one of the ship's systems, and this can have an impact on other systems. The role of maintenance of machines and equipment, and other facilities is very important in supporting the operation of a machine. The main motor support system on a ship helps the main engine operate according to its function, namely, providing power to the propeller to propel the ship. In this case, the application of reliability theory can be used to estimate the chances of a system being able to carry out its functions optimally. Reliability is the probability of an item being able to carry out a predetermined function under certain operating and environmental conditions for a predetermined period. [3]. Reliability analysis of components that support the system in fuel performance does not wait for a failure to occur first, but prioritizes carrying out reliability analysis as a preventive/remedial step to prevent the failure from occurring.

To anticipate failure in the fuel system, reliability analysis can be carried out, its implementation is by identifying how the fuel system failed and the consequences of this incident. Management maintenance needs to be carried out to prevent failure of the system itself. Maintenance management includes prevention (preventive maintenance), repairs (corrective maintenance). Tracing the causes of component or system failure is carried out by evaluating and analyzing the component or system using Fault Tree Analysis (FTA). Fault Tree Analysis is an analysis tool that creates a combination of definite failures in a system. This FTA is useful for describing events in a system [4][5]. Failure Mode Effect Analysis (FMEA), is a technique used to identify and analyze a failure and its consequences to avoid failure experienced by a component [6].

The Weibull distribution is the first step in calculating Mean Time to Failure (MTTF). The Weibull distribution was introduced by Swedish physicist Waloddi Weibull in 1939. The Weibull distribution is a theoretical distribution of continuous random variables that is often used to analyze the reliability of an item. Just like the Gamma and Exponential Distributions deal with reliability issues, the Weibull Distribution is most frequently used [7]. After carrying out the Weibull distribution, the values obtained are processed to obtain the reliability index, reliability rate, and Mean Time To Failure (MTTF) value of a component.

Methodology

In this research, qualitative analysis and quantitative analysis were carried out. Qualitative analysis was obtained from primary data, namely, interviews with ship operators and experts in their fields related to research data including the Fault Tree Analysis (FTA) method and discussion of questionnaires to be processed using the Failure Mode and Effect Analysis (FMEA) method assisted by using the Excel program to make calculations easier. Quantitative analysis is obtained from secondary data, namely data from the logbook, which will be processed using the Weibull distribution. This research was carried out through several stages of methods.

a. Failure Analysis Using the Fault Tree Analysis (FTA) Method

Fault Tree Analysis (FTA) is a method for identifying failures in a system, which are caused by component failures or other failure events simultaneously or individually. In addition, fault tree analysis identifies failure modes, causes of failure, and the impact of functional failures that will be caused by components in the KM main engine fuel system. Rainbow Solar. The process of constructing a fault tree is a top-down approach, which means that the analysis begins by identifying the causes of top events from the highest level to the lowest level sequence, which is usually identified using symbols such as And or Or Gate [8].

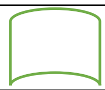
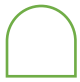
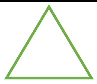
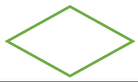
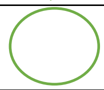
Symbols	Remarks
	*Top Event*
	*Logic Event OR*
	*Logic Event AND*
	*Transferred Event*
	*Undeveloped Event*
	*Basic Event*

Figure 1. Symbols for Fault Tree Analysis

Remarks:

a. *Top event / primary event*, is a failure condition. The symbol may apply to intermediate events.
b. *OR gate*, an output event will occur if at least one event occurs.
c. *AND gate*, an output event will occur if and only if all input events occur.
d. *Transferred-out event*, the point where the fault tree can be split into sub-fault trees.
e. *Transferred-in event*, the point at which the fault tree can begin as a transferred-out continuation.
f. *Undeveloped event* (*uncompleted event*), is an event that requires further reduction until a basic event is discovered.
g. *Basic event* is the cause of failure.

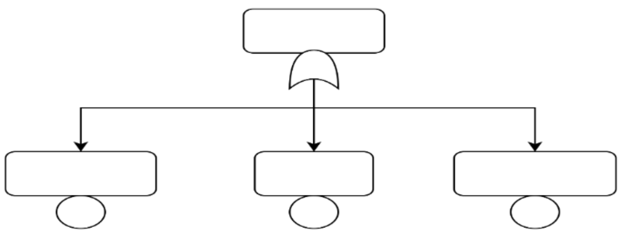


Figure 2. Fault Tree Analysis Diagram

b. Analysis and Calculations Using the Failure Mode and Effect Analysis (FMEA) Method

After creating a fault tree analysis in this chapter, data processing using the Failure Mode and Effect Analysis (FMEA) method aims to obtain critical components which are failures which will be analyzed further. in this case it will start from identifying the problem that has been created using fault tree analysis which will be used as a research object, a description of the respondents relating to the research data, and a discussion of the results of the questionnaire to be processed using the Filure Mode and Effect Analysis (FMEA) method with the help of the Microsoft Excel program.

Risk priority number (RPN) is the result of multiplying the weights of severity, occurrence, and detection. These results will be able to determine critical components. RPN = Severity (S) x Occurance (O) x Detection (D)

- **Severity, Occurrence, Detection value assessment**

In the failure mode assessment, there are 3 assessments: the first is severity, the second is occurrence, and the third is detection.

Table 1. Severity [9]

Hazard Level	Criteria	Level
Very 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 an early warning/detection	9
Very high	Damage to components causes the machine to stop and lose its main function	8
High	Component failure results in the system shutting down, but the engine is 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	Components are considered bad, but component performance is still good, and the system and machine are still running perfectly	2
No Influence	No influence	1

Table 2. Occurrence [9]

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
Often occurs (1)	High occurs in less than 5-8 operations	8
Often occurs (2)	Quite high 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 occurred	Never happened	1

Table 3. Detection [9]

Detection	Criteria	Level
Impossible To Detect	It will not be controlled and/or detected as a potential cause 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 Very Low	Very low to detect potential causes and subsequent types of failure	7
For Detected Low	Low to detect potential causes and subsequent types of failure	6
For Medium Detection	It is hardly easy to detect potential causes and subsequent types of failure	5
For Middle and Upper Detection	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/Visibly	It can be expected that their frequent occurrence will result in the detection of potential causes and events	1

c. Making a Maintenance Schedule Using Weibull Distribution Calculations

The Weibull distribution is one of the statistical data models that has a wide reach in life testing and reliability theory, with its main advantage being that it provides failure accuracy with very small samples or data. The Weibull distribution is a continuous distribution that is widely used, especially in the fields of reliability and statistics, because of its ability to approach various types of data distributions. The Weibull distribution is a distribution that has an important role, especially in matters of reliability and maintainability analysis. The Weibull distribution has, over the years, become one of the statistical data models that has a wide range of applications in life testing and reliability theory, with its main advantage being that it provides failure accuracy with very small samples [10].

Calculation of the probability density function (PDF) or probability from the Weibull distribution with 3 parameters as follows [11]:

$$f(t) = \frac{\beta}{\eta} \left(\frac{t-\gamma}{\eta}\right)^{\beta-1} \exp^{-\left[\frac{t-\gamma}{\eta}\right]^{\beta}}$$

Where: β = beta parameters
η / α = eta parameters
γ = gamma parameters
t = the first time it failed

Determining the failure rate function from the Weibull Distribution can be expressed using the following formula [11]:

$$\lambda(t) = \frac{\beta}{\eta} \left[\frac{t-\gamma}{\eta}\right]^{\beta-1}$$

Reliability function [11] The Weibull distribution can be expressed using the following formula:

$$R(t) = e^{-\left[\frac{t-\gamma}{\eta}\right]^{\beta}}$$

Determining the Mean Time To Failure (MTTF) value from the Weibull Distribution with 3 parameters is as follows [12]:

$$MTTF = \eta \bullet \Gamma\left(\frac{1}{\beta} + 1\right) + \gamma$$

Result and Discussion

a. Failure Analysis Using the Fault Tree Analysis (FTA) Method

Fault tree analysis identifies failure modes, causes of failure, and the impact of functional failure that will be caused by components in the main engine fuel system of the 2800 GT Container Ship. With this failure tree, all failure modes that occur in the fuel system can be identified, thereby providing additional information to the technician in charge of handling the system. The following fault tree analysis scenario can be seen in Figure 4.1. From Figure 4.1. FTA analysis of the fuel system can be seen as a whole. The diagram below has branches that influence or cause the failure of the main engine fuel system of the 2800 GT Container Ship.

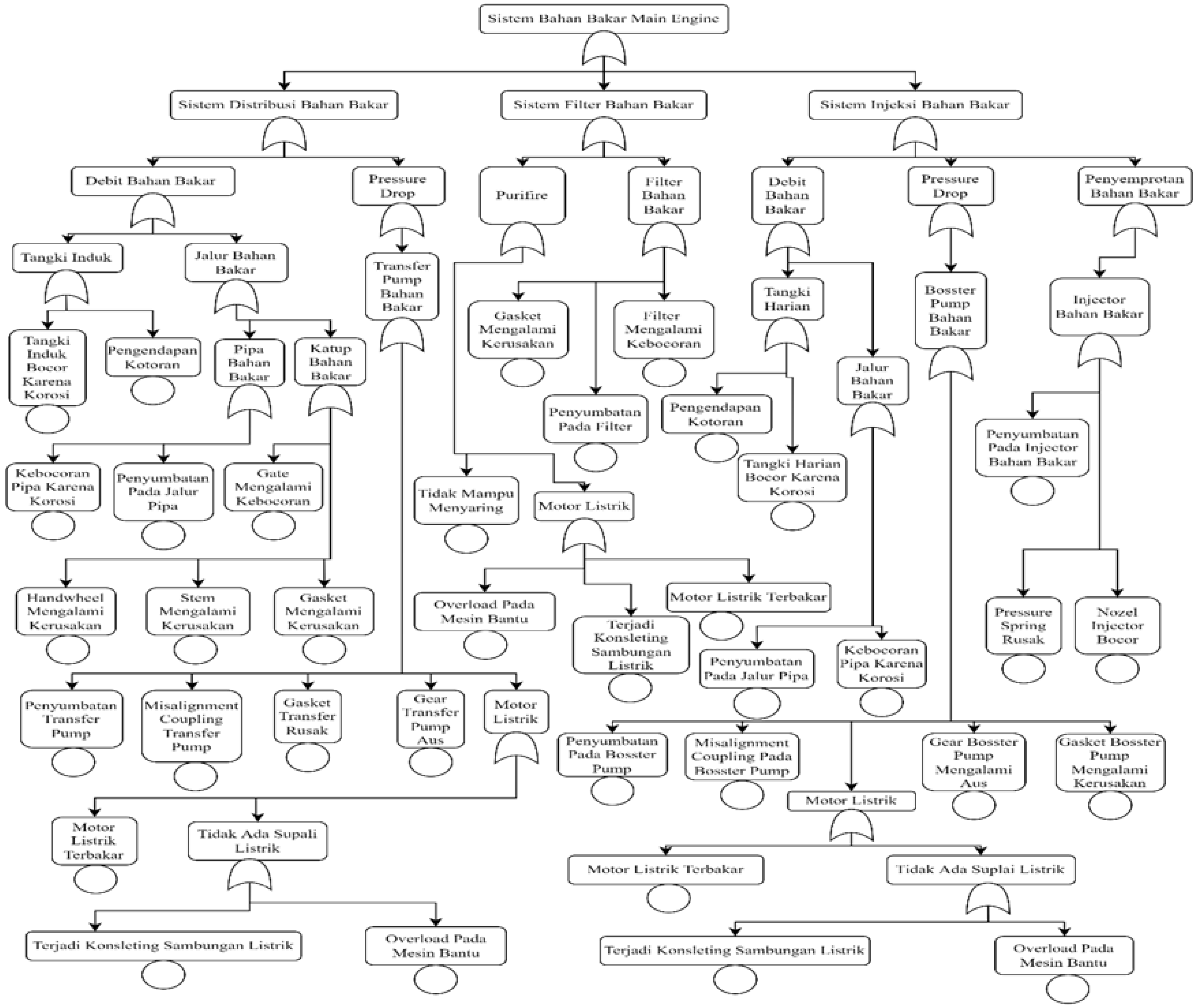


Figure 3. Fault Tree Diagram for the Main Engine Fuel System of a 2800 GT Container Ship.

b. Analisa dan Perhitungan Menggunakan Metode *Failure Mode and Effect Analysis* (FMEA)

Data processing using the Failure Mode and Effect Analysis (FMEA) method aims to obtain critical components that are failures, which will be analyzed further. In this case, it will start from identifying the problem that will be used as the research object, a description of the respondents relating to the research data, and a discussion of the questionnaire results to be processed using the Filure Mode and Effect Analysis (FMEA) method with the help of the Microsoft Excel program.

After analyzing using the fault tree analysis method, failure tree data was obtained, and a questionnaire was created to find the highest value of critical components. Table 4 shows the content of the questions in the interview questionnaire distributed.

Table 4. Fuel system failure modes

No.	Components name	Failure mode
1.	Main Tank	• The main tank has a leak due to corrosion • Deposition of dirt in the main tank
2.	Fuel Pipe	• Pipes experience leaks due to corrosion • Dirt blockage in pipes
3.	Pipe Valves	• The gate experiences leaks due to corrosion • The handwheel is damaged due to corrosion • Stem suffers damage due to corrosion • Gaskets experience damage due to component age
4.	Transfer Pump	• Dirt blockage in the transfer pump • Overload on auxiliary machines • A short circuit occurs in the electrical connection • Electric motors burn out due to the age of the components • Coupling misalignment in the transfer pump • The transfer pump gasket is damaged • Transfer pump gears suffer wear and corrosion
5.	Daily Tank	• Daily tanks experience leaks due to corrosion • Daily deposition of dirt in the tank
6.	Strainers	• Not capable of filtering • Overload on auxiliary machines • A short circuit occurs in the electrical connection • Electric motors burn out due to the age of the components
7.	Booster Pump	• Dirt blockage in the booster pump • Overload on auxiliary machine • Short circuit in the electrical connection • The electric motor burns due to component age • Coupling misalignment in the booster pump due to vibration • Booster pump gasket damaged due to component age • Booster pump gear worn and corroded
8.	Filter	• There is a dirt blockage in the filter • The filter leaks due to sedimentation capacity or overload • The gasket is damaged due to the age of the component
9.	Injector	• There is a dirt blockage in the injector nozzle • The pressure spring breaks due to component age • The injector nozzle is leaking due to the age of the components
10	Injector Pipe	• Injector pipe leaks due to corrosion • Dirt blockage in pipes

Table 5. RPN calculation results

No	Components Name	Failure Mode	RPN
1	Injectors	There is a blockage in the injector nozzle	392
2	Filter	There is a blockage in the filter	288
3	Purifiers	Purifier unable to filter	288
4	Transfer Pump	Blockage in the transfer pump	288
5	Booster Pump	Booster pump gear worn out	200
6	Injectors	The injector nozzle is leaking	200
7	Booster Pump	Blockage in the booster pump	175

8	Transfer Pump	Transfer pump gear worn out	120
9	Fuel Pipe	Pipe blockage	75
10	Injector Pipe	Injector pipe blockage	40
11	Injectors	Pressure spring is broken	40
12	Daily Tank	Daily tank has a leak	36
13	Booster Pump	The booster pump gasket is damaged	27
14	Filter	The filter is leaking	24
15	Booster Pump	Coupling misalignment in booster pump	21
16	Transfer Pump	Coupling misalignment in transfer pump	20
17	Pipe Valves	Gate experiencing a leak	20
18	Main Tank	Deposition of dirt in the main tank	20
19	Transfer Pump	The transfer pump gasket is damaged	18
20	Main Tank	Main tank has a leak	12
21	Transfer Pump	There is a short circuit in the electrical connection	10
22	Transfer Pump	Electric motorcycle burns	9
23	Booster Pump	There is a short circuit in the electrical connection	9
24	Booster Pump	Electric motorcycle burns	9
25	Purifiers	Electric motorcycle burns	9
26	Purifiers	Electrical short circuit occurs	9
27	Purifiers	Overload on auxiliary engines	8
28	Transfer Pump	Overload on auxiliary engines	8
29	Daily Tank	Daily tank settling	8
30	Booster Pump	Overload on auxiliary engines	7
31	Injector Pipe	Injector pipe has a leak	6
32	Fuel Pipe	The pipe has a leak	5
33	Pipe Valves	The handwheel is damaged	4
34	Pipe Valves	The stem is damaged	4

c. Mitigation analysis of the main causes of failure

1. Use good fuel

Good/clean fuel quality is very important for the circulation of the fuel system and for the main engine. If the fuel quality is not good/dirty, it can disrupt the circulation of the fuel system and will affect the performance of the main engine. If the fuel system and main engine are disturbed, it will cause huge losses; therefore, good/clean fuel quality is very important. [13].

2. Make a maintenance schedule

Maintaining the performance of the machine or its supporting system is very important, as if the performance of the machine or its supporting system cannot be maintained, then performance will decrease. Maintenance is a series of activities to repair, replace, and modify a component or system [14].

3. Schedule component replacement

When a component is past its usage limit, its performance/reliability will decrease and can disrupt the performance of other systems. Therefore, if the age of a component has passed the limit, it is hoped that it will be replaced immediately, to maintain or not interfere with the performance of other components. Reliability is the chance that a system/component can operate without failure (success) within a certain period under certain operating conditions [15].

d. Making Maintenance Schedules Using Weibull Distribution Calculations

Maintenance is an action to maintain or maintain a system or repair a system, so that when it is used, the system can work according to its function. A maintenance schedule for a system is very important because it supports optimal system performance. A maintenance schedule is an effort to regulate improvements to maintain continuity of production or performance, so that it can produce optimal performance through a maintenance schedule.

e. Fuel System Component Damage Time Data

Data on the time of fuel system failure is data that shows the fuel system cannot carry out its function. There is a need for maintenance or maintenance or replacement of components due to damage.

Table 6. Component failure data

No	Components Name	Time of Failure	Number of Failures
1	Transfer Pump	5950, 6640.	2
2	Booster Pump	4235, 4720, 4460.	3
3	Purifier	5530, 7030.	2
4	Injector	2200, 2250, 2103, 2010,2420, 2050.	6
5	Filter	1120, 967, 910, 930, 925, 1735, 1230, 1530, 1755, 1230, 1270.	11

Data collection was carried out on the 2800 GT Container Ship by looking at the engine log book (engine section activity book) to determine the operating hours of each main engine fuel component and failure time data in the period 2016-2022.

Tabel 7. Analisa Data Waktu Kerusakan

No.	Components Name	Realibility Parameters	Distribution Value
1.	Transfer Pump	Weibull 3 Parameters	
		Beta	1,2019
		Eta	1133,413
		Gamma	5414,50
2.	Booster Pump	Weibull 3 Parameters	
		Beta	2,060
		Eta	775,113
		Gamma	3811,50
3.	Purifier	Weibull 3 Parameters	
		Beta	2
		Eta	3647, 055
		Gamma	3207, 40
4.	Injector	Weibull 3 Parameters	
		Beta	5,0535

		Eta	882,93
		Gamma	1535,19
5.	Filter	Weibull 3 Parameters	
		Beta	1,025
		Eta	476,318
		Gamma	893,0

Table 8. Calculation results of fuel system components

No	Components Name	Time (t)	Probability density function (pdf)	Reliability R(t)	Failure rate	MTTF (hours)
1	Transfer Pump	5950	0,000601	0,66	0,001062	6476,556
2	Booster Pump	4235	0,00104	0,749	0,0014	4498,211
3	Purifier	5530	0,000232	0,66	0,00349	6439,529
4	Injector	2010	0,000114	0,93	0,00066	2290,779
5	Filter	967	0,00176	0,86	0,00176	1363,454

After obtaining damage time data from the logbook, the next step is to process the data using Relx 2009 software, which contains Weibull. Next, by inputting component operating hours data based on the 2800 GT Container Ship logbook, the Weibull distribution will be automatically obtained, which produces shape parameters, scale parameters, and location parameters. These three parameter values are used to obtain the probability density function (PDF), failure rate, and mean time to failure (MTTF) values for each component. You can see the value results for each component.

1. Transfer Pump
   Data on component failure times are: 5950, 6640. From this data, the probability curve can be found. Using the "Relex" Weibull distribution software with 3 parameters, namely:
   a. Shape parameters (β) = 1,2039
   b. Scale parameters (η) = 1133,413
   c. Location parameters (γ) = 5414,50

a. Probability density function:

$$f\,(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1} e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

$$f\,(t) = \frac{1{,}2039}{1133{,}413}\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039-1} e^{-\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039}}$$

$$f\,(t) = 0.000601$$

b. Reliability value R(t):

$$R\,(t) = e^{-\left(\frac{t-\gamma}{\eta}\right)^{\beta}}$$

$$R\,(t) = e^{-\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039}}$$

$$R\,(t) = 0{,}66$$

c. Failure rate:

$$\lambda\,(t) = \frac{\beta}{\eta}\left(\frac{t-\gamma}{\eta}\right)^{\beta-1}$$

$$\lambda\,(t) = \frac{1{,}2039}{1133{,}413}\left(\frac{5950-5414{,}50}{1133{,}413}\right)^{1{,}2039-1}$$

λ (t) = 0,001062

d. Mean Time to Failure (MTFF):

$$\text{MTFF} = \eta \bullet \Gamma\left(\frac{1}{\beta} + 1\right) + \gamma$$

$$\text{MTFF} = 1133{,}413 \bullet \Gamma\left(\frac{1}{1{,}2039} + 1\right) + 5414{,}50$$

MTFF = 6476,556 hours

Conclusion

Based on the results of calculations and discussion of the 2800 GT main engine fuel system using the Failure Mode and Effect Analysis (FMEA), Fault Tree Analysis (FTA), and Weibull distribution reliability calculations for making schedules, it can be concluded that:

1. The fuel system of the 2800 GT Container Ship, which has the highest value of critical components that often cause damage, is the Injector with a failure mode where there is blockage in the injector nozzles, Filter, Purifier, Transfer Pump, and Booster Pump. Mitigation analysis is made based only on fuel system components that have the highest 5 critical values that cause the most damage. There are 3 main mitigations overall, the first is using good fuel. Good/clean fuel quality is very important for the circulation of the fuel system and for the main engine. Poor/dirty fuel quality can disrupt the circulation of the fuel system and affect the performance of the main engine. Secondly, create a maintenance schedule to maintain the performance of the machine or its supporting equipment. Maintenance is required. For the third, create a component replacement schedule. When a component is past its usage limit, its performance/reliability will decrease and can disrupt the performance of other systems.
2. Proper predictable maintenance of the main engine fuel system based on reliability value calculations. The reliability value of the Transfer Pump components is 5950 hours with a reliability of 0.66, Booster Pump 4325 hours with a reliability of 0.749, Purifier 5530 hours with a reliability of 0.66, Injector 2010 hours with a reliability of 0.93, and Filter 967 hours with a reliability of 0.86. Mean Time to Failure (MTTF) component value. MTTF value of Transfer Pump components 6476.556 hours, Booster Pump 4498.211 hours, Purifier 6439.529 hours, Injector 2290.779 hours, Filter 1363.454 hours.

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