International Journal of ASRO
Volume 13, Number 04, pp.74-86
03 Oktober 2022

OPTIMIZATION OF PREVENTIVE MAINTENANCE AND REPLACEMENT INTERVAL OF CRITICAL COMPONENTS IN THE CUMMINS KTA 38D DIESEL GENERATOR

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ABSTRACT

The Cummins KTA 38D brand diesel generator is a ship's power generation equipment owned by a supplier to warship electrical needs both at base or in operation. Based on damage report data from 2016 - 2022, the percentage of diesel generator damage reached 38.5% of the total damage to all ship equipment. The results of the analysis using the FTA method cause the failure of the diesel generator to be caused by one of the failure factors in the supporting sub-systems,both from the electrical sub-system, fuel sub-system, air sub-system, fresh water sub-system, seawater sub-system, the lubricant sub-system and the control sub-system were damaged. Calculation using FMECA, there are five critical components based on the RPN value with a "high" risk rating, namely the Body Cover Pump component with the risk of corrosion (205), the Impeller component with the risk of corrosion/cracking (260.5), the Cooler tube component with the risk of leakage (264,7), Mechanical Seal component with risk of damage/leak (192.8), Rectanguler Seal component with risk of leak (196). With a reliability approach and analysis of total cost replacement age preventive maintenance with a minimum reliability limit of 55.84%. It can be proposed maintenance intervals for Body Cover Pump components at 980 running hours with an increase in reliability of 30.87% and maintenance cost savings reaching 14.57%, Impeller components at 1581 running hours with an increase in reliability of 35.79% and maintenance cost savings reaching 29.28%, Cooler tube components at 979 running hours with an increase in reliability of 26.06% and maintenance cost savings reaching 16.40%, mechanical seal components at 1290 running hours with an increase in reliability of 33,20% and savings in maintenance costs reaching 22,57%, the rechtangular seal component on 979 running hours with an increase in reliability of 31.67% and savings in maintenance costs reaching 38.88%.

Keywords: *FTA, FMECA, Reliability dan Total Cost Replacement Age*

1. INTRODUCTION

A tanker type of warship is designed for fuel distribution and liquid logistics supplies at sea (fleet on replenishment at sea). To support the vital role carried out by the ship, the readiness of the ship's technical condition is an absolute requirement that must be properly maintained. One of the equipment has a vital role on the ship is a diesel generator. Due to the high age and operating hours of the diesel generator, the potential for damage will increase. Damage diesel generators caused by damage a component cannot be known with certainty because each component has a different reliability and rate of damage.

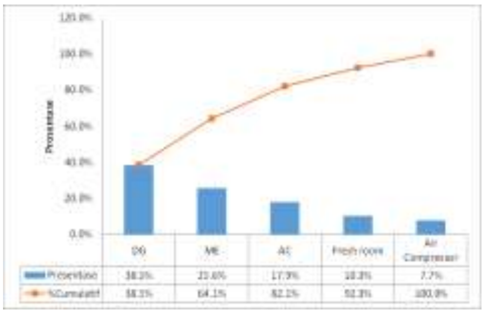


Figure 1. Graphics of equipment damage

According to ship damage report data, the percentage of damage for Cummins KTA 38D diesel generator is highest reached at 38.5% from total equipment damage that occurred during 2016 – 2022. The graphic of equipment damage is presented in figure 1.

There are several weaknesses in the maintenance of the diesel generator system carried out by ship personnel, these weaknesses are:

a. The form of maintenance card for the planned maintenance system is not yet available.
b. Incomplete equipment manual handbook
c. Spare parts and tools maintenance equipment not available
d. Lack of understanding of maintenance by operators,
e. Operators are still having trouble finding the root cause of equipment damage,
f. The equipment operated continuously until a breakdown occurs.

This study aims to determine the factors that cause failure, and optimize preventive maintenance on components that have high criticality in the Cummins KTA 38D diesel generator in order to reduce the number of breakdowns and efficiency in terms of costs using the FTA, FMECA, reliability and total cost replacement age method.

2. MATERIAL AND METHODE

2.1 Diesel Genartor

The diesel generator is a ship's equipment useful for supplying the electricity needs of the ship. The diesel generator is a combination of a diesel engine and a generator. A diesel engine is a combustion engine with a combustion process that occurs within the engine itself (internal combustion engine) and combustion occurs because pure air is compressed (compressed) in a combustion chamber (cylinder) so that high-pressure air and high heat are obtained, along with being sprayed. the fuel is atomized so that combustion occurs.

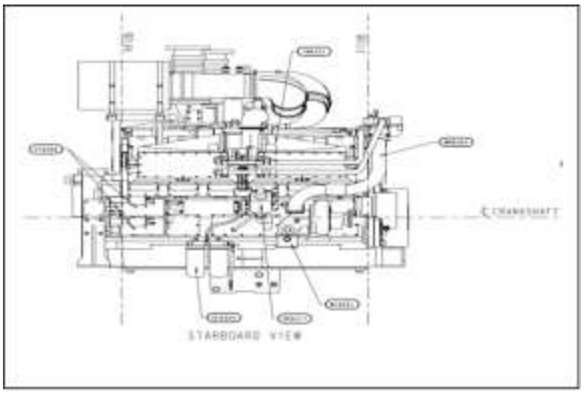


Figure 2. Engine Cummins KTA 38D

Table 1. Specification engine data of diesel generator Cummins KTA 38D

Diesel	**Generator**
Merk : CUMMIN	Merk : STAMFORD
Engine No : 41183836	Type : LVM634G1
Model : KTA38-D(M)	AVR : MX321
SO No : S060179	Volt : 400
Advert : 880 kw	Phase : 3
Max. : 970kw	KVA : 1100
Idle speed : 650~750	Rpm : 1500
Rpm : 1500r/min	Ampere : 1587.8
Produck : 2013	Freq : 50Hz
Manufacture: Chongqing Cummins China	ID No : X13A021703

2.2 Reliability Diagram Block

To evaluate for the reliability of a component or system, the first is make model the component or system into a reliability block diagram. The composition of the reliability block diagram of the system consists of structural forms, namely:

a. Series structure

A series structure is a system structure where the system is said to be damaged if one of its components is damaged.

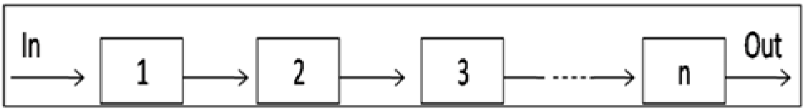


Figure 3. Series structure

b. parallel structures

A parallel structure is a system structure where the system still functioning if at least one component is functioning or it can be said that the system is damaged if all components are damaged.

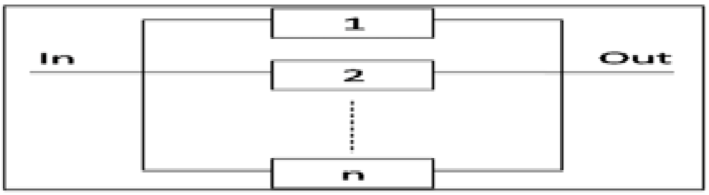


Figure 4. Parallel structure

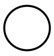
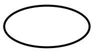
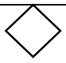
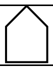
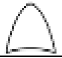
2.3 Fault Tree Analysis (FTA)

Fault Tree Analysis (FTA) is a method of deductive analysis by describing numerical graphs and analyzing how damage can occur and what are the chances of damage (Blanchard, 2004). The FTA steps in a system are as follows:

a. Identify the most important events in the system (top level events).
b. Create a fault tree (fault tree).
c. Analyze the fault tree (fault tree)

The symbols used in fault tree analysis are as follows:

Table 1. Symbol of Fault Tree Analysis

Symbols	**Description**
	Basic Event
	Intermediate Fault Event
	Undeveloped Event
	External Event
	Top Event
	Logic event End gate
	Logic event Or gate
	Exclusife Event

2.4 Failure Mode Effects and Criticality Analysis (FMECA)

FMECA is a development of FMEA by considering the level of criticality associated with the impact of the component failure mode. This criticality level is analyzed based on a combination severity and probability of occurrence The analysis may be performed according to the following scheme.

a. Definition and delimitation of the system (which components are within the boundaries of the system and which are outside).
b. Definition of the main functions (missions) of the system.
c. Description of the operational modes of the system.
d. System breakdown into subsystems that can be handled effectively.
e. Review of system functional diagrams and drawings to determine interrelation- ships between the various subsystems. These interrelations may be illustrated by drawing functional block diagrams where each block corresponds to a sub-system.
f. Preparation of a complete component list for each subsystem.
g. Description of the operational and environmental stresses that may affect the system and its operation. These are reviewed to determine the adverse effects that they could generate on the system and its components.

Table 2. Severity, Occurance, and Detection rating

Severity	**Occurance**	**Detection**	**Score**
Hazardous Without Warning	> 1 in 2	Absolutely Impossible	10
Hazardous With Warning	1 in 3	Very Remote	9

Very High	1 in 8	Remote	8
High	1 in 20	Very Low	7
Moderate	1 in 80	Low	6
Low	1 in 400	Moderate	5
Very Low	1 in 2000	Moderately High	4
Minor	1 in 15000	High	3
Very minor	1 in 150000	Very High	2
None	< 1 in 1500000	Almost Definitely	1

Component criticality analysis based on failure mode/failure mode using a risk matrix according predetermined criteria. The final results obtained are items that are included in the critical components, namely components that are included in the "high" rating of risk based on the risk matrix. The overall results of the analysis of the FMECA method will be presented in the form of an FMECA Worksheet.

Table 3. Severity Level.

Severity Level		
Kategori	**Ranking**	**Definition**
Catastrophic	8,1-10	Cause system shutdown.
Critical	6,1-8	The system cannot function as specified.
Marginal	4,1-6	The system has decreased function performance.
Negligible	2,1-4	The system can function with little risk.
Minor	1-2	The system can function with negligible risk.

Table 4. Occurrence Level.

Occurrence Level		
Event Frequuency	***Occurrence Rating***	**Definition**
Frequent	8,1-10	Often occur
Probable	7,1-8	Very likely
Occasional	5,1-7	Commonly occurs
Remote	3,1-5	Rarely occurs
Improbable	1-3	Impossible to happen

Table 5. Risk Matrix

PROBABILITY		***SEVERITY***				
		Minor	***Negligible***	***Marginal***	***Critical***	***Catastropic***
	Frequent	MEDIUM	HIGH	HIGH	HIGH	HIGH
	Probable	MEDIUM	MEDIUM	MEDIUM	HIGH	HIGH
	Occasional	MEDIUM	MEDIUM	MEDIUM	MEDIUM	MEDIUM
	Remote	LOW	MEDIUM	MEDIUM	MEDIUM	MEDIUM
	Improbable	LOW	LOW	LOW	LOW	LOW

2.5 Reliability

Reliability is defined as the probability of a system having performance according to the function required within a certain period of time (Ebeling, 1997). The time that elapses from a component entering operation until it fails the first time is called the time to failure (TTF). For the purposes of damage analysis, TTF can be considered as a random variable (Ponidi, 2015)

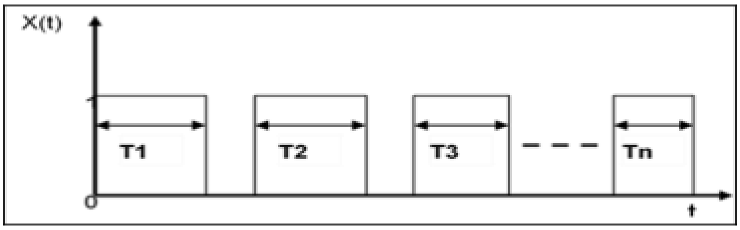


Figure 5. State Variabel X(t) & TTF

The probability of damage occurring when T < t is expressed by F(t), with the Cumulative Distribution Function (CDF) as follows (Artanto, Budisantoso, & Ahmadi, 2016):

$$F(t) = P\{T \leq t\} = \int_0^t (t)dt$$

Then the reliability function is expressed by the following equation

$$R\,(t) = 1 - P\{T \leq t\} = 1 - F(t)$$

In analyzing the reliability of a system, the term Mean Time To Failure (MTTF) is often used in characterizing the reliability which is expressed by the following equation

$$MTTf = \mu = \int_0^\infty t\,f\,(t)dt$$

To state how easy it is for an item to fail and can last up to time T, known as the damage rate, it can be written as follows:

$$\lambda(t) = \frac{f(t)}{R(t)}$$

The damage rate can be divided into three periods (burn in period, useful life period and wear out period) which is commonly called the bathub curve.

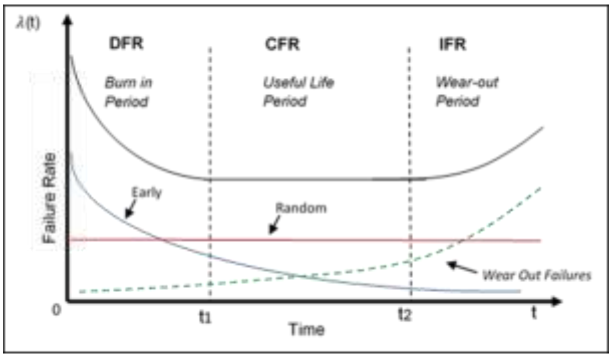


Figure 6. The Bathtub Curve

Based on the distribution classification above, examples of suitable probability models are:

a. Distribution of Decreasing Failure Rate (DFR)

Is the Weibull distribution with λ (t) = a.t b for b < 0, with negative memory.

b. Distribution of Constant Failure Rate (CFR)

Is an Exponential distribution with λ (t) = λ, memoryless property.

c. Distribution of Increasing Failure Rate (IFR)

Is the Weibull distribution with λ (t) = a.t b for b > 0, with the positive property of memory.

2.6 Probability Distribution

The Weibull distribution can describe the condition of the failure rate of components both in the DFR, CFR and IFR areas through variations in the shape parameter values. The Weibull distribution can be written in the form of two or three parameters (Jardine A. S., 1973). While the 3-parameter Weibull distribution has functions including:

Reliability function :

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

Failure rate function:

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

Probability Density function (PDF)

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

MTTF (Mean Time to Failure) :

$$\text{MTTF} = \gamma + \eta\Gamma(1 + \tfrac{1}{\beta}))$$

β = Shape Parameter , β > 0

η = Scale Parameter, η > 0

γ = Location Parameter

Γ = Gamma function.

MTBF *(Mean Time Between Failure)* :

$$\text{MTBF} - \left(\frac{Total\ Working\ Hours}{Frequency\ Failure}\right)$$

MTTR *(Mean Time To Repaire) :*

$$\text{MTTR} - \left(\frac{Total\ Break\ Down\ Hours}{Frequensi\ Break\ Down}\right)$$

2.7 Preventive Maintenance Mode

Improvement of reliability can be achieved by way of preventive maintenance. According to Ebeling (1997), the reliability model assumes that the system returns to its new condition after undergoing preventive maintenance. Reliability at time t is stated as follows

$R_m(t) = R(t)$ untuk 0≤ t ≤ T

$R_m(t) = R(T).R(t-T)$ untuk T≤ t < 2T

T = time interval for damage prevention replacement

Rm (t) = system reliability with preventive maintenance

R(t) = system reliability without preventive maintenance

R(T) = first preventive maintenance reliability probability

R(t-T) = probability of reliability between time t-T after the system is returned to its initial state at time T.

In general, the equation is

$R_m(t) = R(T)^n . R(t - nT)$ for nT≤ t ≤ (n+1)T, where n= 1,2,3…ect.

n = Number of Treatments
R_m (t) = Reliability with preventive maintenance
R(T)^n = Reliability probability up to n maintenance intervals
R(t-nT) = Reliability probability for the time t-nT of the last preventive maintenance action

In the replacement age model, the expected total replacement cost per unit of time for preventive replacements performed after the t_p age of the part.

Some of the similarities in replacement age are as follows:
The cost of failure cycle (C_f)can be calculated using the equation:

$$C_f = (\text{Technician Cost} + \text{Consequential cost} + \text{Component cost})(\ )xT_f$$

Meanwhile, the preventive cycle cost (C_p) can be calculated using the equation

$$C_p = (\text{Technician Cost} + \text{Component cost})xT_p$$

Calculation of Total Failure Cost (Tc) can be calculated using the equation:

$$Tc = \frac{C_f}{t_f + T_f}$$

C_f= Cost of failure cycle
t_f= MTBF(MTTF)
T_f= MTTR

Calculation of Total Preventive Cost (Tc) is obtained by using the equation:

$$Tc = \frac{(C_p x Rt_p) + \{C_f x(1 - Rt_p)\}}{(t_p x\ Rt_p) + \{t_f\ x\ (1 - Rt_p)\}}$$

t_p = Preventive replacement time interval per unit time
C_f = Damage replacement costs.
C_p = Preventive replacement cost.
t_f = Time required for replacement due to damage.
R_{tp} = Reliability of cycle i when tp.

Based on the book Technical Manual No. 5-698-5 entitled: Survey of Reliability and Availability Information For Power Distribution, Power Generation, and Heating, Ventilating & Air Conditioning (Hvac) Components for Commercial, Industrial, and Utility Installations issued by Headquarters Department Of The Army, value The recommended diesel generator reliability is according to Table 6.

3. RESULTS AND DISCUSSION

Based on direct observation, guidance from the Cummins KTA 38D engine manualbook and interviews with respondents and experts, there are 7 (seven) systems that support the operation of diesel generators arranged in series structure.

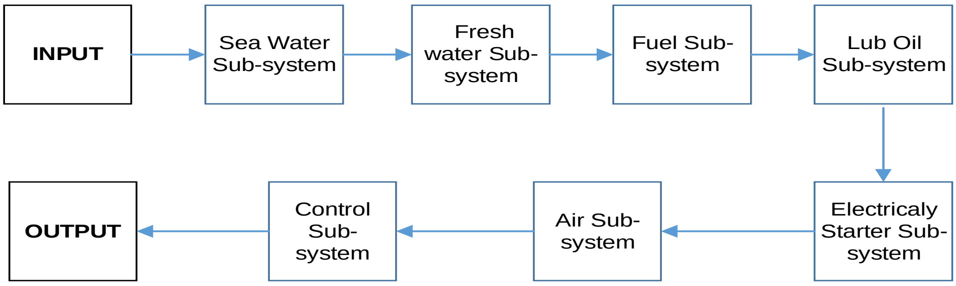


Figure 8 : Block Diagram of Diesel Generator

Acccording the block diagram of diesel generator system has a series structure, where the system is said to be damaged if one of its components is damaged and the system is said to be good if all components are in good condition

3.1 Faul Tree Analysis of Diesel Generator

In the FTA method, the failure of the diesel generator is a top event, the diesel generator operational support systems are developed into a fault tree to find the factors that cause the diesel generator to fail. Factor analysis diesel generator failure can be caused by one of the existing systems. The relationship/logic event of the diesel generator failure factors is to use an OR gate. This shows that the failure of the diesel generator can be caused by one of the failure factors. For detail of factor cause diesel generator fail on figure 10.

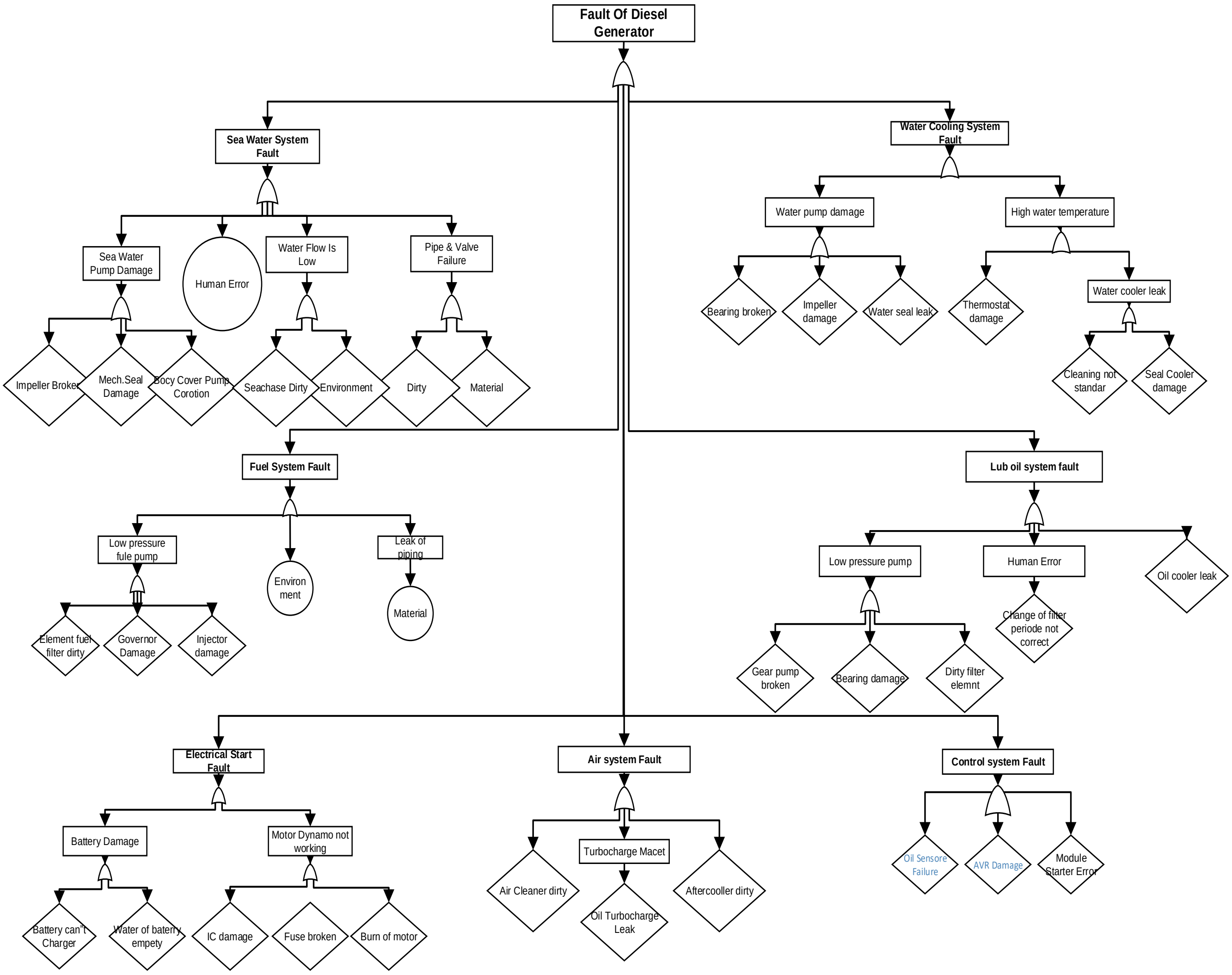


Figure 9. Fault Tree Diagram of Diesel Generator

3.2 FMECA of Diesel Generator

The diagram in figure 9, shows which components are the cause of the sub-system on the diesel generator that affects engine performance. To find out the failure in detail using the Failure Mode Effect and Citical analysis which is applied to the diesel genartor system. The diesel generator system is divided into 7 (seven) sub-systems, namely fresh water sub-system, seawater sub-system, air sub-system, fuel sub-system, lubricant sub-system, electric start sub-system and control sub-system.

a. Sea water sub-system, function each component are of tube coole for heat absorber coolant, impeller for make faster in and out fluid, gasket pump for body casing insulator, Casing cover for protective rotary component pump, Mechanical seal for obratction fluid leakage, strainer for filtering sea water waste, shaft SW pump for pass on rotary moment from driver, and bearing SW pump for keep friction between shaft rotary and body casing.

b. Coolant water sub-system, function each component are, bearing for keep friction between shaft rotary and body casing, seal oil and water for prohibit oil and water get involved, thermostate for keep stability water temperature, rectanguler seal HE for obstauction fluid leakage, and heat excahanger tube for heat absorber coolant,

c. Fuel oil sub-system, function each component are, element fuel filter for filtering fuel sludge, main shaft fuel pump for pass on rotary moment from driver, o-seal drive shaft and seal wire for obstuction fuel leakage, and injector for fuel spraying to combution chamber

d. Lub oil sub-system, function each component are bushing oil pump for vibration muffle, element oil filter for filtering oil sludge, and seal oil heat exchanger for leakage oil inhibitor,

e. Air intake and exhaust Sub-system, funtion each component are air cleaner for filtering air waste, aftercooler for absorb heat of air intake, seal rectanguler ring for air leakage inhibitor and bushing turbocharger for vibration muffle and oil leak inhibitor

f. Elelctricaly starter sub-system, function each component are, battery for electric power storage, and modul starter for regulating starting engine process

g. Control sub-system, function ecah component are, AVR for electrically controlling fuel and Engine oil sensor for read oil temperature.

The FMECA process included components failure mode, failure cause, effects of the failure on the transformer/network and recommendations were formulated to curb future failure. The criticality analysis of each failure mode was performed by assigning to each failure mode a Risk Priority Numbers (RPN), and the results of the entire FMECA process is represented in table 6. Summarizes the failure modes of diesel geneator components each sub system, failure causes, effects of component failure of the diesel genator units or the entire grid and the Risk Priority Numbers based on how severe the effects of a failure are, how frequent a fault occurs and how easy is it to detect the failure before it occurs. Risk Priority Numbers assignments to failure modes are referred to as criticality analysis and specify the critical nature of each component failure. Sample calculation RPN on Tube cooler sea water is ;

RPN

$$= \left(\frac{6+7+7+6+8+8+8+7}{8}\right) \times \left(\frac{7+6+7+6+8+9+8+7}{8}\right) \times \left(\frac{4+3+5+5+6+7+6+5}{8}\right)$$

= (7,1) x (7,3) x (5,1)

= 264,7

Table 6. FMECA worksheet

No	Item	Function	Failure Mode	Failure Causes	Failure Effect	S	O	D	RPN
W1	Tube Cooler Sea Water	Heat absorber coolant	Mechanical	Tube cooler corrosion	Coolant and sea water mixed	7.1	7.3	5.1	264.7
W2	Impeller	Make Faster in/0ut fluid from pump	Mechanical	Impeller corrosion and crack	Suction and press pump can"t work perfection	8,1	7.1	4.5	260.5
W3	Gasket pump	Body casing insulator	Mechanical, thermal	Gasket damage	Permeate water from pump	3.9	6.4	4.6	114.3
W4	Body Cover	Protective rotary componen pump	Material, Mechanical	Material corrosion	Pump can't vaccum	6.6	7.5	4.1	205.0
W5	Mechanical Seal	Obstruction fluid leakage	Mechanical	Mech.Seal damage	Pump suction not perfection	6,1	8.1	3,9	192.8
W6	Strainer	Filtering sea water waste	Mechanical, material	Material corrosion	Sludge go into cooling water	5.5	6.1	3.5	117.9
W7	Shaft SW Pump	Pass on rotary moment from driver	Mechanical	Wear out and corrosion of shaft	impeller not balance occure of vibration	8.0	2.3	6.1	110.3
W8	Bearing SW pump	Fiction keeping between shaft rotary and body casing	Mechanical	Bearing broken and worn out	Pump suction not perfection	5.5	5.1	4.4	123.3
W9	Bearing Coolant Pump	Fiction keeping between shaft rotary and body casing	Mechanical	Bearing broken and worn out	Pump suction not perfection	5.3	4.4	4.8	109.1
W10	Seal Water Coolant Pump	Prohibit oil and water get involved	Mechanical, thermal	Solidify of seal or damage	less of pump suction	7.3	2.9	5.6	117.2
W11	Seal oil Coolant Pump	Prohibit oil and water get involved	Mechanical, thermal	Solidify of seal or damage	Pump suction not perfection	6.8	3.3	5.5	120.7
W12	Thermostat	Keep Stability water temperature	Mechanical, thermal	Termostate can"t work	Coolant temperature Overheating	6.5	2.6	6.3	106.6
W13	Rectanguler Seal HE	Obstruction fluid leakage	Mechanical, thermal	Solidify of seal or damage	Leakage coolant	6.1	8.0	4.0	196.0
W14	Heat Exchanger	Heat absorber coolant	Mechanical, thermal	Tube HE corrosion	Coolant and sea water mixed	8.0	2.5	5.9	117.5
W15	Element Fuel Filter	Filtering Fuel Sludge	Mechanical	Element filter clogged	Less of fuel pressure	7.0	7.0	2.1	104.1
W16	Main Shaft Fuel Pump	Pass on rotary moment from driver	Mechanical	Shaft worn out	Gear pump can"t rotatri occure vibration	8.1	2.1	5.9	101.4
W17	O-Seal Drive Shaft	Obstruction fuel leakage	Mechanical, thermal	Solidify of seal or damage	Pump suction not perfection	7.1	7.3	5.1	264.7
W18	Seal Wire	Obstruction fuel leakage	Mechanical, thermal	Solidify of seal or damage	Pump suction not perfection	8,1	7.1	4.5	260.5
W19	Injector	Fuel spraying to chamber	Mechanical	Injector Shim worn out	High of exhaust temperatur	3.9	6.4	4.6	114.3
W20	Bushing Oil pump	Vibration muffle	Mechanical	Bushing worn out	Crude noise and oil leak	6.6	7.5	4.1	205.0
W21	Element oil Filter	Filtering oil Sludge	Mechanical	Element filter clogged	Less of oil pressure	6,1	8.1	3,9	192.8
W22	Seal oil Heat Exchanger	Leakage oil inhibitor	Mechanical, thermal	Solidify of seal or damage	Oil Leakage	5.5	6.1	3.5	117.9
W23	Battery Accu	Electric Power Storage	thermal, Electrical	Less of accu water or element damage	No electrik power to starting engin	8.0	2.3	6.1	110.3
W24	Gear pinion motor	Pass on rotary power of starter	Mechanical	Knocked gear or fault	Flywheel can<t turning	5.5	5.1	4.4	123.3
W2	Air Cleaner	Filtering air waste	Mechanica	Element filter	Decreasing volume of air	5.	4.	4.	109.

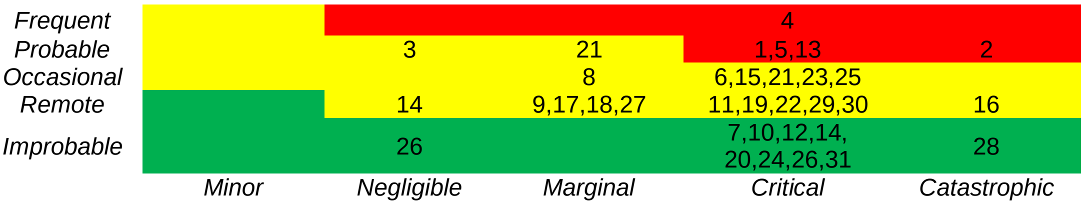
No	Item	Function	Failure Mode	Failure Causes	Failure Effect	S	O	D	RPN
5			l	clogged		3	4	8	1
W26	Aftercooler	Absorb heat of air intake	Mechanical, thermal	Aftercooler corrosion	Air intake temperatur high	7.3	2.9	5.6	117.2
W27	Seal Rectanguler	Air Leakage inhibitor	Mechanical, thermal	Solidify of seal or damage	Air leakage	6.8	3.3	5.5	120.7
W28	Bushing TC	Vibration muffle and oil leakage inhibitor	Mechanical	Bhusing worn out	Crude noise and oil leak	6.5	2.6	6.3	106.6
W29	AVR	Electricaly Controlling fuel	Thermal, Electrical	Short Circuit	Engine rotation unstable	6.1	8.0	4.0	196.0
W30	Engine oil sensor temp.	Read oil temperature	Thermal, Electrical	Short Circuit	Engine can"t start	8.0	2.5	5.9	117.5
W31	Modul Starter	Regulating starting engine process	Thermal, Electrical	Short Circuit	Engine can"t start	7.0	7.0	2.1	104.1
RPN Value = 125,5									

The highest RPN shows the components on which much attention should be tilted. Any 7 (seven) component have the highest RPN values their are impeller, tube cooler sea water, casing cover, battery accu, mechanical seal, strainer and seal rectanguler heat excahanger

Table 7. Risk Matrix

No	Komponen	*Consequency*		*Risk Level*
		Severity	***Occurrence***	
W1	Tube Cooler Sea Water	*Critical*	*Probable*	*High*
W2	Impeller	*Catastrophic*	*Probable*	*High*
W3	Water Seal	*Negligible*	*Probable*	*Medium*
W4	Body Cover Pump	*Critical*	*Frequent*	*High*
W5	Mechanical Seal	*Critical*	*Probable*	*High*
W6	Strainer	*Marginal*	*Occasional*	*Medium*
W7	Shaft SW Pump	*Critical*	*Improbable*	*Low*
W8	Bearing SW Pump	*Marginal*	*Occasional*	*Medium*
W9	Bearing Coolant Pump	*Marginal*	*Remote*	*Medium*
W10	Seal Water Coolant Pump	*Critical*	*Improbable*	*Low*
W11	Seal oil Coolant Pump	*Critical*	*Remote*	*Medium*
W12	Thermostat	*Critical*	*Improbable*	*Low*
W13	Rectanguler Seal HE	*Critical*	*Probable*	*High*
W14	Heat Exchanger Tube	*Critical*	*Improbable*	*Low*
W15	Element Fuel Filter	*Critical*	*Occasional*	*Medium*
W16	Main Shaft Fuel Pump	*Catastrophic*	*Remote*	*Medium*
W17	O-Seal Drive Shaft	*Marginal*	*Remote*	*Medium*
W18	Seal Wire	*Marginal*	*Remote*	*Medium*
W19	Injector	*Critical*	*Remote*	*Medium*
W20	Bushing Oil pump	*Critical*	*Improbable*	*Low*
W21	Element oil Filter	*Critical*	*Occasional*	*Medium*
W22	Seal oil Heat Exchanger	*Critical*	*Remote*	*Low*
W23	Battery Accu	*Marginal*	*Occasional*	*Medium*
W24	Gear pinion motor	*Critical*	*Improbable*	*Low*
W25	Air Cleaner	*Critical*	*Occasional*	*Medium*
W26	Aftercooler	*Critical*	*Improbable*	*Low*
W27	Seal Rectanguler ring	*Marginal*	*Remote*	*Medium*
W28	Bushing TC	*Catastrophic*	*Improbable*	*Low*
W29	AVR	*Critical*	*Remote*	*Medium*
W30	Engine oil sensor Temperatur	*Critical*	*Remote*	*Medium*
W31	Modul Starter	*Critical*	*Improbable*	*Low*

Table 8. Risk mapping



	Minor	*Negligible*	*Marginal*	*Critical*	*Catastrophic*
Frequent				4	
Probable		3	21	1,5,13	2
Occasional			8	6,15,21,23,25	
Remote		14	9,17,18,27	11,19,22,29,30	16
Improbable		26		7,10,12,14, 20,24,26,31	28

RPN calculations and risk mapping for critical components of diesel generators are have effect of engine running is shutdown, which have an RPN value above the average and have a risk with a "High" rating. So that the components that can be categorized as critical components of diesel generators.

Table 9. Critical Components

No	Item	Function	Failure Mode	Failure Causes	Failure Effect	Risk Level	RPN
W1	Tube Cooler Sea Water	Heat absorber coolant	Mechanical	Tube cooler corrosion	Coolant and sea water mixed	High	264.7
W2	Impeller	Make Faster in/0ut fluid from pump	Mechanical	Impeller corrosion and crack	Suction and press pump can"t work perfection	High	260.5
W4	Body Cover	Protective rotary componen pump	Material, Mechanical	Material corrosion	Pump suction not perfection	High	205.0
W5	Mechanical Seal	Obstruction fluid leakage	Mechanical	Mech.Seal damage	Pump suction not perfection	High	192.8
W13	Rectanguler Seal HE	Obstruction fluid leakage	Mechanical, thermal	Solidify of seal or damage	Leakage coolant	High	196.0

3.2 Determination of Maintenance Time Interval

Based on the report damage and repair equipment, the data between damage and the length of time for repairs can be seen in Table 10. The following is a recapitulation of component TTF and TTR data.

Table 10. TTF and TTR data of Critacal Component

No	Body Cover Pump		Mech.Seal		Rech. Seal		Impeller		Cooler Tube	
	TTF	TTR	TTF	TTR	TTF	TTR	TTF	TTR	TTF	TTR
1	341	1:20	672	4:00	824	2:30	2217	4:45	594	9:30
2	672	4:30	384	4:20	945	4:15	801	4:30	1422	6:55
3	384	5:30	1138	4:45	448	3:15	1922	5:45	868	4:15
4	1138	1:15	2041	3:00	680	4:10	1946	4:15	786	5:15
5	1173	1:35	2318	5:15	121	3:30	1130	4:20	1279	7:45
6	2463	6:10	1822	3:45	235	2:45	1203	4:35	797	6:55
7	723	2:30	1200	4:15	3633	2:35	2195	4:40	845	8:35
8	1822	5:15	911	4:50	2313	2:15	1478	4:55	1211	7:05
9	1072	2:00	1523	4:25	1045	4:25	1071	5:30	1531	6:45
10	1523	1:25	2742	5:30	506	4:05	2407	4:10	1974	6:40
11	2742	1:40	1479	4:10	1220	2:45	1462	3:15	995	9:00
12	479	1:30	851	3:15	362	2:20	1305	3:55	2287	7:45
13	1223	4:30	803	3:35	1231	1:35	1893	3:50	1403	9:50
14	2370	5:45	2198	3:25	1203	1:30	2265	4:00	1669	8:15
15	804	1:00	1975	3:00	1211	2:05			929	5:55
16	579	1:45	1158	3:20	1875	2:25			1453	7:05
17	2891	1:50			1358	2:40			722	5:20
18	1781	1:05			995	2:30			1031	6:50
19					1537	4:30			2621	8:50
20					1179	2:05			3005	5:00
21					851	2:15				
22					803	1:45				
23					311	1:40				
24					2394	1:50				
25					1188	3:15				
26					758	1:55				
27					680	2:15				
28					777	2:45				
29					1874	2:50				

Data processing using the Weibull 6++ program all component obtained the distribution and component parameters according to table 11.

Table 11. Distribution and Parameter of Critacal Component

No	Component	Distribution	Parameter	
1	Body Cover Pump	Weibull 2	β	1.3242
			η	1472.7243
2	Mechanical Seal	Weibull 2	β	2.2074
			η	1647.1035
3	Rechtanguler Seal HE	Weibull 2	β	1.669
			η	1255.9585
4	Impeller	Weibull 2	β	3.4539
			η	1847.9991
5	Cooler Tube	Weibull 3	β	1.2226
			η	907.299
			γ	545.995

After conduct the distribution of TTF data through the Weibull++6 program, the parameters β, η and γ are obtained, so the MTBF/MTTF value of each component can be determined. Based on maintenance and repair journals and interviews with chief engginer, the body cover pump, impeller and cooler tube components are repairable components so MTBF is used to calculate them. As for the mechanical seal and rectangular seal components, they are components that are non-repairable (cannot be repaired) so that the data used uses MTTF calculations. The following is a recapitulation of MTBF, MTTF, MTTR values and reliability of critical diesel generator components in table 12.

Table 12. Recapitulation of MTBF/ MTTF, MTTR values and reliability

No	**Component**	**MTBF**	**MTTR**	**R(t)**	**F(t)**	**λ(t)**
1	Body Cover pump	1343.3	2.81	0.4126	0.5874	0.000796035
2	Mechanical Seal	1458.7	4.08	0.4653	0.5347	0.001013060
3	Rectangular Seal	1122.1	2.71	0.4367	0.5633	0.001101017
4	Impeller	1663.9	4.58	0.4986	0.5014	0.001300763
5	Cooler Tube	1371.1	7.17	0.3290	0.6710	0.002232385

In order to meet the minimum reliability requirements for diesel generator equipment of 0,5584, a trial and error method was simulated. The results of calculating the reliability of the body cover pump components before and after preventive maintenance based on the Weibull distribution are in accordance with the following table 13.

Table 13. Reliability of the body cover pump components before and after preventive maintenance

t (Jam Putar)	**R(t)**	**n**	**t-nT**	**R(T)^n**	**R(t-nT)**	**Rm(t)**
0	1.0000	0	0	1.0000	1.0000	1.0000
300	0.8855	0	300	1.0000	0.8855	0.8855
400	0.8369	0	400	1.0000	0.8369	0.8369
500	0.7873	0	500	1.0000	0.7873	0.7873
600	0.7375	0	600	1.0000	0.7375	0.7375
700	0.6883	0	700	1.0000	0.6883	0.6883
800	0.6404	0	800	1.0000	0.6404	0.6404
900	0.5940	0	900	1.0000	0.5940	0.5940
980	0.5582	1	0	1.0000	1.0000	1.0000
1000	0.5494	1	20.0	1.0000	0.9822	0.9822
1100	0.5069	1	120.0	1.0000	0.8977	0.8977
1200	0.4665	1	220.0	1.0000	0.8205	0.8205
1300	0.4284	1	320.0	1.0000	0.7500	0.7500
1343.3	0.4126	1	363.3	1.0000	0.7213	0.7213
1400	0.3925	1	420.0	1.0000	0.6855	0.6855
1500	0.3589	1	520.0	1.0000	0.6265	0.6265
1600	0.3276	1	620.0	1.0000	0.5727	0.5727
1700	0.2984	1	720.0	1.0000	0.5234	0.5234
1800	0.2713	1	820.0	1.0000	0.4784	0.4784

Graph of reliability comparison before and after preventive maintenance at interval t = 1290 as shown in the following figure

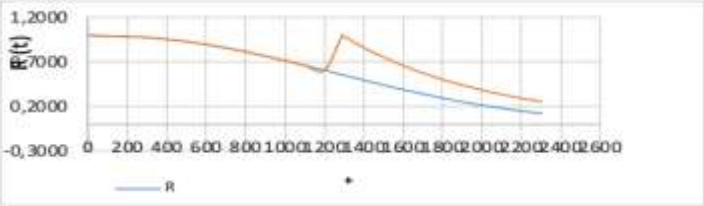


Figure 10. Graph body cover pump component

Following are the results of calculating the reliability of the alls components before and after preventive maintenance based on the Weibull distribution according to table 14.

Table 14. Recapitulation reliability

Component	Before Preventive Maintenance	After Preventive Maintenance	Increasing Reliability	Time Interval	Preventive Maintenance
Body Cover Pump	0.4126	0.7213	30.87 %	980	Inspection
Impeller	0.4653	0.7973	33,20 %	1290	
Cooler Tube	0.3290	0.5896	26.06 %	979	
Mechanical Seal	0.4986	0.8565	35.79 %	1581	Component change
Rechtangular Seal	0.4367	0.7534	31.67 %	859	

In its application, preventive maintenance requires a fee called preventive cost, this cost arises because of maintenance on machines that have been adjusted to a set schedule. The preventive costs that arise will be compared with the costs without preventive maintenance which are called failure costs where these costs are a consequence of unexpected damage which causes the machine to stop during operation. Based on the calculation of the total cost of preventive maintenance, it can be estimated that maintenance cost savings when using preventive maintenance. The results of the calculation of maintenance cost savings for each critical component are as follows

Table 15. Recapitulation Total Cost

Component	Before Preventive Maintenance	After Preventive Maintenance	Cost Saving
	Tc/Jam	Tc/Jam	
Body Cover Pump	Rp 6.236,-	Rp 5.327,-	14,57%
Impeller	Rp 13.719	Rp 9.702,-	29,28%
Cooler Tube	Rp 23.800,-	Rp 19.895,-	16,40%
Mechanical Seal	Rp 6.164,-	Rp 4.773,-	22,57%
Rechtangular Seal	Rp 2.204,-	Rp 1.347,-	38,88%

4. CONCLUSION

The results of the analysis using the FTA method cause the failure of the diesel generator to be caused by one of the failure factors in the supporting sub-systems,both from the electrical sub-system, fuel sub-system, air sub-system, fresh water sub-system, seawater sub-system, the lubricant sub-system and the control sub-system were damaged. Calculation using FMECA, there are five critical components based on the RPN value with a "high" risk rating, namely the Body Cover Pump component with the risk of corrosion (205), the Impeller component with the risk of corrosion/cracking (260.5), the Cooler tube component with the risk of leakage (264,7), Mechanical Seal component with risk of damage/leak (192.8), Rectanguler Seal component with risk of leak (196). With a reliability approach and analysis of total cost replacement age preventive maintenance with a minimum reliability limit of 55.84%. It can be proposed maintenance intervals for Body Cover Pump components at 980 running hours with an increase in reliability of 30.87% and maintenance cost savings reaching 14.57%, Impeller components at 1581 running hours with an increase in reliability of 35.79% and maintenance cost savings reaching 29.28%, Cooler tube components at 979 running hours with an increase in reliability of 26.06% and maintenance cost savings reaching 16.40%, mechanical seal components at 1290 running hours with an increase in reliability of 33,20% and savings in maintenance costs reaching 22,57%, the rechtangular seal component on 979 running hours with an increase in reliability of 31.67% and savings in maintenance costs reaching 38.88%.

ACKNOWLEDGEMENT

The author is very grateful for the support of the Indonesian Navy, and also thanks to the STTAL Surabaya Indonesia Naval College of Technology for providing the necessary resources to carry out this research work. The authors also thank anonymous reviewers and the editorial board for their many insightful comments, which have enhanced this article significantly.

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