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Criticality Analysis for Research Vessel Machinery System Maintenance Strategy Study Case: RV. Baruna Jaya

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Abstract

In recent years, marine survey operations such as survey operations for underwater communication cables and tsunami early warning systems have become annual activities involving research vessels in Indonesia, including RV. Baruna Jaya. Along with the increasing age of the ship, it will be followed by a decrease in the performance of the machinery system. The machinery system is maintained to maintain the desired performance by ship users. However, with many machinery system equipment and limited resources, an analysis is needed to prioritize which equipment or components need regular maintenance and monitoring activity. By classifying all assets into a hierarchical form and performing a risk-based criticality analysis, equipment will be prioritized based on the probability of failure and the level of consequence. By determining the probability of failure of a component based on historical data and reference failure data and determining the consequences for health safety (HS), production (P), Environment (E), and Containment (Cn), the risk would be obtained. This analysis obtained as many as 766 pieces of equipment and components consisting of 38 rotary equipment, 45 static equipment, 196 piping components, and 487 instruments. The risk analysis obtained as many as 23 (3%) of equipment in H (high), 138 (18%) in the M (medium) condition, and 605 (79%) in the L (low) condition. The criticality results determined that 161 (21%) equipment in H & L conditions would be carried out planned maintenance, and 605 (79%) equipment in low conditions would be carried out unplanned maintenance.

1. Introduction

In recent years, marine survey operations in Indonesia have become an annual activity. Some of these include surveys of underwater communication cables [1] and surveys of tsunami early warning systems [2]. To support these operations, a ship with special capabilities is needed to carry out marine survey operations. One of the ships that have this capability is a research vessel. Indonesia has several research vessels, one of them being the RV. Baruna Jaya Research Vessel. Baruna Jaya Research Vessel consists of 5 vessels: RV. Baruna Jaya I, II, III, IV, and VIII. This research vessel was assigned to meet the needs of marine survey operations in Indonesia. Supporting the ship' s operation, many mechanical and electrical systems support the ship. In general, ships are supported by fuel oil systems, lubricating oil systems, freshwater cooling systems, seawater cooling systems, ballast systems, bilge systems, fire suppression systems, central air conditioning cooling systems, domestic systems, and so on [3]. Each system has main equipment and supporting components to carry out its functions, such as pumps, compressors, valves, pressure indicators, etc. The function of these systems, equipment, and components will later contribute to the ship' s operation, so the condition and performance of these systems, equipment, and components must be maintained. However, along with the ship' s age, the decline in function and performance is inevitable. The frequency of occurrence of damage will increase, and it will take a lot of repair time which will require a lot of effort and money to restore it to its standard condition. In addition, serious damage, especially to critical equipment such as the ship's propulsion system, can also cause damage to other ship' s components due to vibrations and abnormal systems [4]. This is necessary for emergency repairs to be carried out immediately, so it is necessary to prepare more time, energy, and costs to restore the function of the original propulsion system.

In a marine survey operation conducted by RV. Baruna Jaya, some of the equipment was also damaged. It was necessary to repair and replace spare parts at sea. One example was during the Indonesia Tsunami Early Warning System (Ina-TEWS) survey in October 2021, during the deployment of buoys in Sunda and Bengkulu, and during the recovery buoy on Mount Anak Krakatau. During the 13 days of the voyage, nine damages occurred. Most of the damage did not significantly affect the ship's voyage and survey operations. Still, some of the damage required reparation and maintenance, such as leaks in the hydraulic pipe of lifting equipment and overheating due to problems in the cooling system. Some potentials that cause damage can still occur in the form of minor or major damage that affects the ship's voyage and survey operations. Therefore, good maintenance is needed to maintain the performance and function of the ship's systems, equipment, and components so that they are maintained according to the desired performance of ship users. With the increasing age of ships, the number of existing equipment and components, and the increasing frequency of damage, while the available resources are limited, it is necessary to have a special strategy to map out proper maintenance to all these equipment and components. One of them is by applying the critical analysis method first.

Several applications of criticality analysis methods have been applied to several objects, including thermal power plants. At the thermal power plant, a criticality analysis is carried out using one of the multi-criteria decision methods, namely the Analytic Hierarchy Process (AHP), by creating a hierarchy based on several levels, including the level of objectives (Ranking of equipment), the level of criteria (Effect on power generation, environment, and safety). Each criterion is determined by its value scale starting from " no impact" to " high impact" , then determines the comparison matrix and the weighting of each criterion, converts the comparison matrix to normal matrix form, determines the comparison of relative importance between the assessment criteria, The comparison matrix is validated for consistency and also the weights of different criteria are calculated. Based on this analysis, nine critical pieces of equipment were ranked, and the top 3 pieces of equipment were obtained: Turbine, Generator, and Fan ID [5]. On wind turbine equipment, a criticality analysis is carried out using the criticality analysis method, which is improved by expansion based on the Euclidean distance from the failure vector. Failure vectors are defined to describe equipment failures. The wind turbine failure vector can be shaped by various variables such as the number of events, economic losses, the difficulty of detection, Effect Severity Rank (ESR), and so on. To eliminate the criticality sensitivity to the range of variables, the failure vector is normalized before calculating the criticality level. The failure vector is weighted to distinguish the different contributions of each variable to the criticality. Based on the ranking of Risk Priority Number (RPN) and Cost Priority Number (CRN), the top 3 critical pieces of equipment obtained in a row are Tower, Gearbox, and Rotor Blade [6]. Several oil and gas sector standards also provide guidelines for component critical analysis, such as Norsok Z-008. Critical analysis is based on risk concerning the Norsok Z-008 standard, previously carried out at a gas central processing plant. From creating a hierarchy or taxonomy of assets, determining the main function, subfunction, redundancy, asset register, probability, consequence, risk matrix, and finally, determining criticality. From this analysis, 28 (4%) of equipment was obtained at the high level, 192 (28%) at the medium level, and 454 (67%) at the low level [7].

In this criticality analysis, equipment and components will be used on a Baruna Jaya research vessel' s system to be determined as maintenance objects. In papers [5] and [6], rotary equipment with several supporting components is used as an object of analysis. In the research with the RV. Baruna Jaya, all rotary and static equipment will be analyzed, including the supporting components in piping and instrument. With a large number of equipment and components, and the failure data of equipment and components is always increasing, it is important to develop an effective and efficient analysis to prioritize the equipment and components. In the paper [7], object maintenance uses a gas-central processing plant with a risk matrix, probability, and consequence criteria based on its company. The probability was determined using reference bank reliability data. The critical analysis using the RV. Baruna Jaya will use the equipment and components from the RV. Baruna Jaya by determining the probability of failure using a combination of historical data and reference data banks. Consequence categories will refer to previous papers, including consequences for health safety, production, environment, etc., but each classification's description will correspond to the available standard. This analysis will refer to the Norsok Z-008 standard. In the scope of the 2017 edition of the Norsok Z-008 standard, guidelines for determining the criticality method can be fundamentally adopted into the ship/maritime industry [8]. In this analysis, steps will be taken to conduct critical analysis, such as determining the hierarchy or taxonomy of assets and the risk level of these assets. By mapping all machinery system equipment and components using a hierarchy or asset taxonomy, this critical analysis will be carried out by mapping the probability of failure using historical failure data and bank reliability data, then mapping the level of consequences on safety, environmental, production, and containment. Next, determine the risk according to the probability of failure and the consequences to get three criticality ratings, namely high (H), medium (M), and low (L).

2. Methods

To get the criticality of the equipment and components of the ship's machinery system, a flowchart is made regarding the steps or stages in conducting a criticality analysis. Figure 1 shows a flowchart of steps or stages in conducting critical analysis on RV. Baruna Jaya' s machinery system.

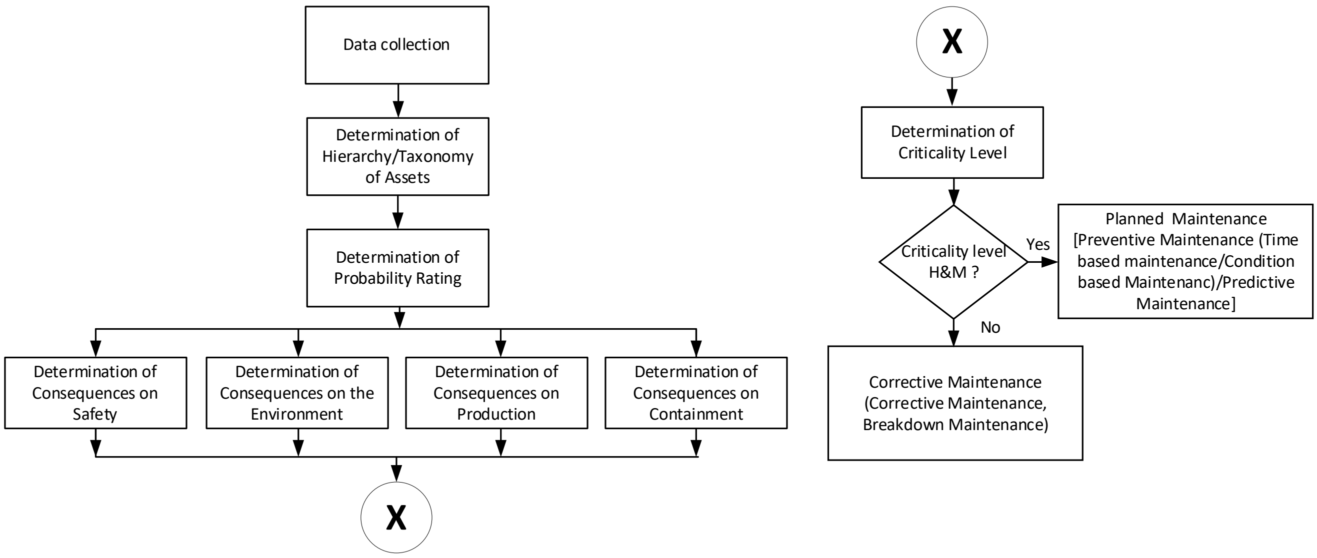

Figure 1. Critical analysis methodology flowchart

2.1. Data Collection

The First step is determining the hierarchical assets. To determine the hierarchical assets, it is important to find each existing system, equipment, and component. So, a design drawing of each system with its equipment and components is required. In this case, a Piping and Instrument Diagram (PID) is needed to determine every detail of equipment and components. The second step is determining the probability of failure. At the stage of determining the probability of failure, historical data on equipment failure during the voyage is needed to determine the value of the failure frequency and estimated failure time of the equipment and components. However, not all equipment or components have failed in their lifetime. So, reference data is needed from a reliability data bank, one of which is the OREDA (Offshore and Onshore Reliability Data) Handbook. The Third step is determining the level of consequences. At this stage, The Material Safety Data Sheet (MSDS) of the fluids contained in the system and some judgments will be used for determining the consequences for Health and Safety (HS), Environment (E), Production (P), and Containment (Cn). The fourth step is determining the critical assets. At this stage, a risk matrix is needed to convert the probability of failure and the level of consequences into a risk. In this analysis, we will use the risk matrix from the Norsok Z-008 standard.

The Baruna Jaya Research Vessel is a vessel used to conduct marine research. Figure 2 shows a picture of the Baruna Jaya Research Vessel, and Table 1 shows the specifications of the Baruna Jaya Research Vessel according to the initial design. PID documents can be used as guidelines for collecting asset data as maintenance objects. Some existing PID documents will be used as guidelines for collecting asset data, and some missing PID documents will be checked in the field to complete the existing data. This critical analysis will be limited to systems directly related to the Main Engine or Propulsion System. Figures 3 and 4 show a picture of the propulsion system configuration and an example of a freshwater cooling system PID. Table 2 shows a list of PID documents used in this analysis.

Figure 2. Baruna Jaya Research Vessel

Table 1. Ship specifications

Vessel Name	Equipment
Launched	1995
GRT	1219 Ton
NRT	365 Ton

LOA	60.40 m
LBP	55.25 m
Width	12.10 m
Depth at Upper Deck	6.5 m
Draft Mean	4.15 m
Main Engine	2 x 1100 HP @850 RPM, Niigata SEMT Pielstick 5PA5L
Auxilliary Engine	1 unit Diesel Generator Baudouin 270 HP @1500 RPM
Main Alternator	2 unit shaft driven generator Leroy Somer @625 KVA
Synchronous Alternator	1 unit Leroy Somer 200 KVA @1500 rpm
Bow Thruster	1 unit Schottel STT 170 LKT – 200 HP @1500rpm
Propeller Type	CPP 4 Blades Renou Dardel type CPP 1504
Fuel Tank Capacity	HSD 190.000 liters, Oil 11.000 liters
Fresh Water Tank Capacity	90.000 liters
Reverse Osmosis	250 liters/hour @clear seawater
Fuel Consumptions	6752 liters/day
Lifting Equipment	1 Unit A Frane Gantry 10 Tons, 2 Unit Side Gantry for CTD, 1 Unit Main Crane (0.75 t for 12 m and 2.5 t for 5 m)

Table 2. List of PID Document

No	System Name	PID Number	PID Name
1	Fresh Water Cooling System	645-P-000-T-576MJ-01-A	Fresh Water Refrigeration Diagram
2	Sea Water Cooling System	645-P-000-T-575MM-01-B	Sea Water Piping Diagram
3	Fuel Oil System	645-P-000-T-335MU-01-B, 645-P-000-T-335SG-01-C	Fuel Oil Distribution Piping System, Fuel Oil Transfer Piping System
4	Lubricating Oil System	645-P-000-T-336SL-01-B	Lubrification Oil Piping Diagram
5	Air Compressed System	645-P-000-T-335MU-01-B	Air Piping Diagram

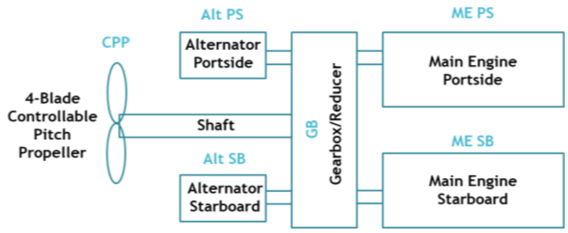

Figure 3. Propulsion system configuration

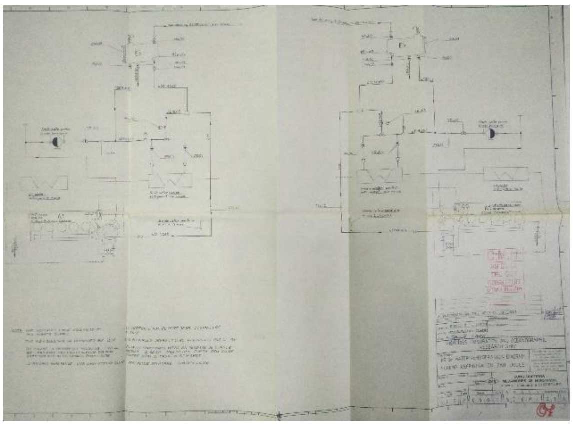

Figure 4. PID Drawing of Freshwater Cooling System

Historical data is needed to determine the failure probability of equipment and components. In 2021, Baruna Jaya Research Vessel number IV conducted a buoy deployment survey twice. The first route of buoy deployment is in the southern sea of Malang (Ina-Buoy MLG) and the Sunda strait (Ina-Buoy SUN) from February to March. The second is to deploy buoys in the Sunda Strait (Ina-Buoy SUN), the western sea of Bengkulu (Ina-Buoy BKG), and recovery buoy on Mount of Anak

Krakatau (Ina-Buoy GAK) during the period of October. During the survey, the ship suffered several damages to the engine system. Figure 5 and 6 shows the frequency of equipment failure on days during the voyage. Table 3 shows historical damage data during the 2nd survey in October 2021. Figure 7 shows some documentation of damage that has been experienced by ships during the survey period of October 2021. The example of asset hierarchy to classify and identify all equipment and components, MSDS to determine the consequence of failure, and risk matrix to convert probability and consequence will be given in detail for each step.

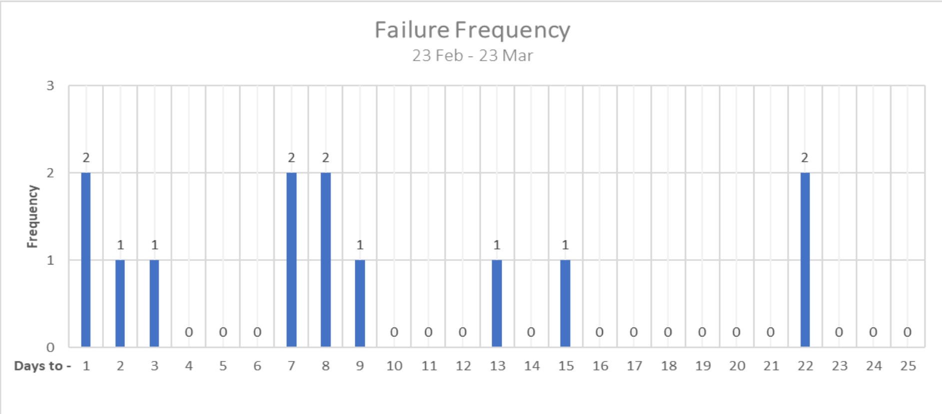

Figure 5. Failure frequency (February-March Period)

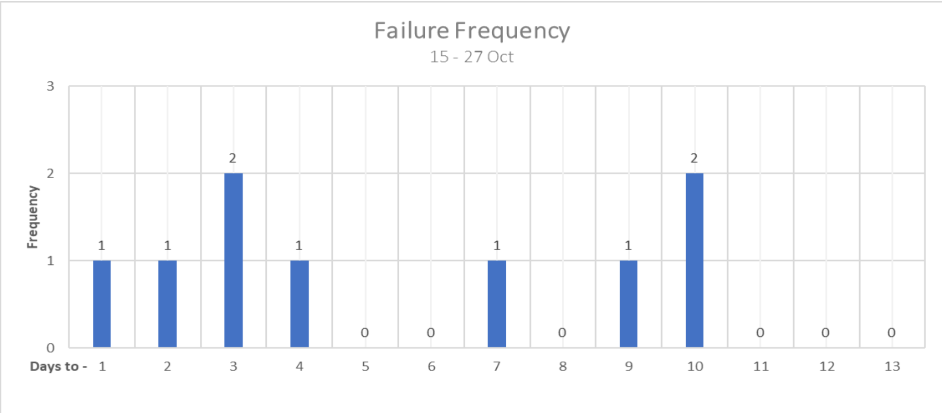

Figure 6. Failure frequency (October Period)

Table 3. Data on damage to ship machinery for the survey period of October

Days to -	Date	f	Equipment	Failure
1	15-Oct-21	1	1. Valve Pump HP Reverse Osmosis Unit	1. Cracks and inelastic springs
2	16-Oct-21	1	1. Heat Exchanger FW & SW ME SB	1. FW leak to SW
3	17-Oct-21	2	1. Membran RO Unit 2. HP RO Unit Pump	1. Leak on the membrane cover 2. Leaks in the joint seal of the piston body and the HP pump body valve
4	18-Oct-21	1	1. SW drivenby ME PS Pump	1. leakage and pressure drop. Damage to the spi housing and impeller axles
5	19-Oct-21	0	-	-
6	20-Oct-21	0	-	-
7	21-Oct-21	1	1. Hidrolis CTD Piping	1. Valve not working
8	22-Oct-21	0	-	-
9	23-Oct-21	1	1. Valve Selenoid AC central	1. Valve not working
10	24-Oct-21	2	1. Expansion Valve AC central 2. Hose hidrolik A-frame/gantry	1. Decreased performance, less than the maximum valve opening. 2. Hydraulic oil leak on the nipple
11	25-Oct-21	0	-	-
12	26-Oct-21	0	-	-
13	27-Oct-21	0	-	-

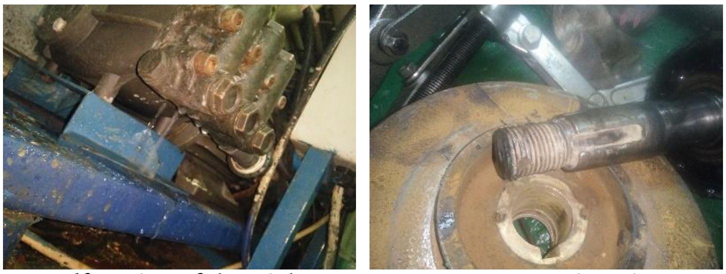

Figure 7. Malfunction of the High Pressure Reverse Osmosis Unit pump (Left), Damage to “ spi” housing and seawater cooling pump impeller axle (Right)

2.2. Determination of Asset Hierarchy or Taxonomy

The purpose of determining this hierarchy or taxonomy is to determine the number and types of equipment and components on the RV. Baruna Jaya so that all maintenance objects can be identified. Taxonomy is the systematic classification of items into general groups based on factors that may be common to some items (location, use, equipment subdivision, etc.) [9]. Each existing system, equipment, and component will be classified according to the hierarchical level, starting from the highest to the lowest level. In addition, at this stage of the asset hierarchy, equipment and components will be classified according to their respective groups based on the hierarchical level created. By the existing standards on Norsok Z-008, this grouping consists of several sub-levels, including Plant, System, Main Function, Subfunction, and component/Tag [8]. In this analysis, the classification of the asset hierarchy will use these levels. Figure 8 below shows an example of an asset hierarchy based on Norsok Z-008.

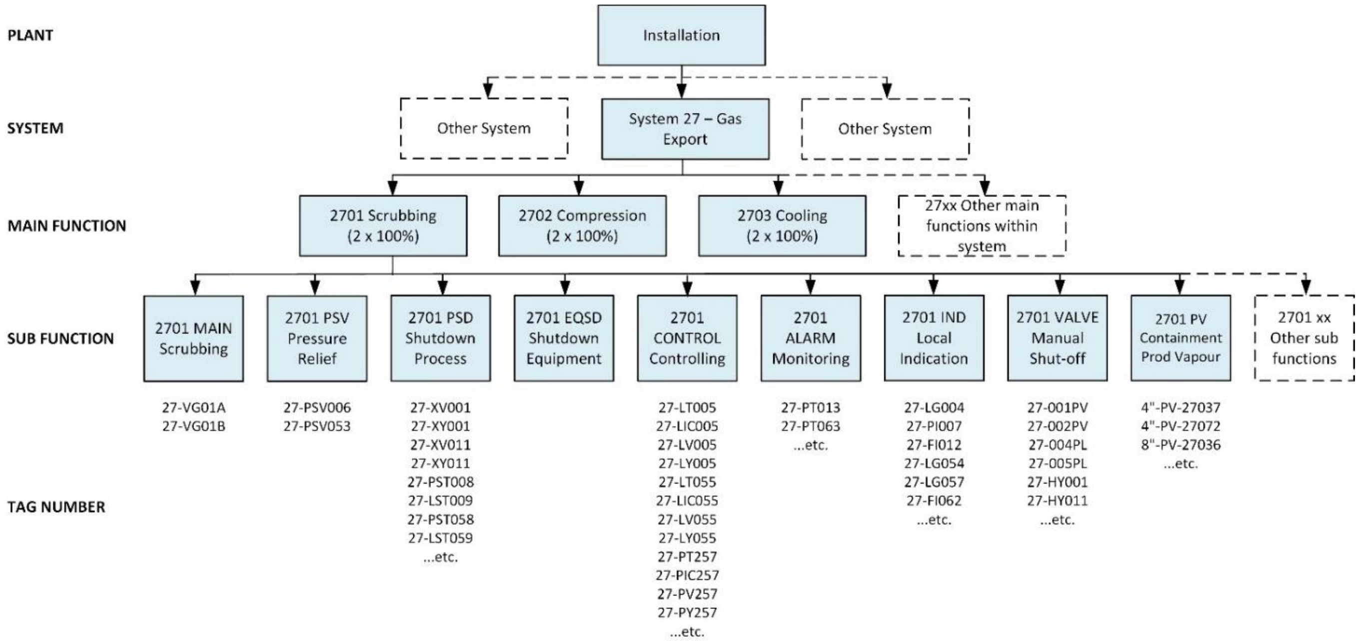

Figure 8. An example of an asset hierarchy based on Norsok Z-008 [8]

2.3. Determination of Probability Rating

The purpose of determining the probability rating is to determine the level of probability of failure of equipment or component in an RV. Baruna Jaya. Probability is the possibility that risk will appear in a certain period. Historical data is usually used to determine the probability of failure [10]. The probability of failure is a necessary parameter in determining risk [11]. The failure of this asset will provide information about how reliable the component is or how likely the component will fail. Processing historical data from the failure of the equipment component during operation can obtain the possible period of this component failure. However, of all the existing components, not all of them have failed. So, to predict the possible failure time of these components, it is necessary to use references from other data. One uses a failure data handbook such as OREDA (Offshore and Onshore Reliability Data) Handbook. OREDA is a collection of data on the reliability of floating building components collected and processed from various companies [12].

2.3.1. Determination based on Mean Time Between Failure

The MTBF formula can be used to determine the failure time of components based on historical data. MTBF is a measure of equipment reliability and the standard of any maintenance and repair work performed. One of the goals of performing maintenance on equipment or components is so that the equipment or components can operate for a long time. This can be seen from the MTBF value [13]. Thus, the higher the MTBF value, the equipment or component has a longer operating time before damage occurs. Meanwhile, if the MTBF value is low, the equipment has a low operating time until damage occurs. The failure rate (λ) and MTBF are formulated as follows [14]:

$$\lambda = \frac{Frequency\ of\ failure}{number\ of operation\ hours} \quad (1)$$

Where λ is the failure rate.
The Mean Time Between Failures (MTBF) can be calculated using the formula:

$$\text{MTBF} = \frac{1}{\lambda} \quad (2)$$

Where MTBF is the Mean Time Between Failures and λ is the failure rate.

2.3.2. Determination based on OREDA

Determining the probability of failure time using reference data will use the failure rate data from the OREDA handbook data. The following is an example of a calculation using OREDA data [7]:

Table 4. Failure Mode and Failure Rate selection

Failure Modes	**Mean Failure Rate (10^6 hours)**
Abnormal instrument reading	4.18
External leakage - Process medium	7.14
External leakage - Utility medium	9.75
Total	21.33

From the data above, it can be determined that the failure rate per year from the LP Separator is as follows:

$$FR_{LPSeparator} = \frac{\text{mean failure rate}}{10^6} \text{ x 8760 hours} \quad (3)$$

$$FR_{LPSeparator} = \frac{21{,}33}{10^6} \text{ x 8760 hours}$$
$$FR_{LPSeparator} = 0.18 \text{ per year}$$

From the failure rate data obtained, the value of the MTBF can be determined as follows:

$$\text{MTBF} = \frac{1}{FR_{LPSeparator}} \quad (4)$$

$$\text{MTBF} = \frac{1}{0.1869}$$
$$\text{MTBF} = 5.35 \text{ years}$$

After determining the probability of failure time is obtained, the next step is to classify it into the probability rating. Table 5 shows the classification of the probability of failure.

Table 5. Probability rating

Nilai	**Indikator**	**Description**	**MTBF (Year)**
F4	Probable	Frequency of failure/year > 1	Mean Time Between Failure 0 - 1
F3	Possible	Frequency of failure/year 0.3 - 1	Mean Time Between Failure 1 - 3
F2	Unlikely	Frequency of failure/year 0.1 - 0.3	Mean Time Between Failure 3 - 10
F1	Rare	Frequency of failure/year < 0.1	Mean Time Between Failure > 10

2.4. Determination of Consequence Rating

The purpose of determining the consequence rating is to determine the level of consequences caused by the failure of equipment and components in the RV. Baruna Jaya. Norsok Z-008 defines a consequence as the result of an event. There may be one or more consequences of an event. Consequences can range from positive to negative. However, the consequences are always negative for the safety aspect. Consequences can be expressed qualitatively or quantitatively. Consequences are categorized into five categories: consequences on health & safety, Environment, Production, Containment, and Cost [8]. In this analysis, a consequence assessment will be carried out according to the category and description of Norsok Z-008, which includes Health & Safety, Environment, Production, and Containment. Tables 6, 7, 8, and 9 show the consequence ratings used to determine the level of consequences of equipment or components when they fail.

Table 6. Consequence Ratings of Health and Safety

Nilai	Indikator	Description
C3	Critical	Potential for serious personnel injuries, Render critical safety systems inoperable.
C2	Serious	Potential for injuries requiring medical treatment, Limited effect on safety systems
C1	Minor	No potential for injuries, No effects on safety

Table 7. Consequence Ratings of Environment

Nilai	Indikator	Description
C3	Critical	Potential for large pollution. > 1 year
C2	Serious	Potential for moderate pollution. One month – 1 year
C1	Minor	No potential for pollution) < 1 month

Table 8. Consequence Ratings of Production

Nilai	Indikator	Description
C3	Critical	Immediate and significant loss of production
C2	Serious	Delayed effect on production or reduced production
C1	Minor	No production loss

Table 9. Consequence Ratings of Containment

Nilai	Indikator	Description
C3	Critical	Flammable media above flashpoint, Highly toxic media, Extremely high pressure/temperature media
C2	Serious	Flammable media below flashpoint, Moderately toxic media, High pressure/temperature media (>100 bar/80 °C)
C1	Minor	Non-Flammable Media, Nontoxic media, Natural/normal pressure/ temperature media

Several appropriate methods can be used to determine the consequences according to the rating. In this analysis, the level of consequences is determined using the fluid's MSDS data or Material Safety Data Sheet. Therefore, the fluid of each system must be identified first. The use of MSDS in this analysis is to determine the level of consequences for Health & Safety, Environment, and containment. Figure 9 is an example of an MSDS from a B30 fuel producer. Meanwhile, the consequences of the estimated loss of production will be assessed using judgment by analyzing the effect of equipment or components when they fail the system.

3. COMPOSITION/INFORMATION

Chemical Name	CAS. No	Concentration (%)
Hydrocarbons, diesel fraction	68334-30-5	60 - 70
Distillate, C8-C26 branched and straight	848301-67-7	< 30
Kerosene, C8-C16 branched and straight alkanes	848301-66-6	< 10
FAME	-	30

4. FIRST AID MEASURES ON ACCIDENT

Step Description :

> Eye contact : If your eyes experience irritation or redness, rinse your eyes with clean water. If these symptoms persist, contact your doctor.

> Skin Contact : Remove contaminated clothing and shoes, and rinse all contaminated body parts with running water.
If the skin surface is injured, wear clean clothes and seek medical attention.
If the surface of the skin is not injured, clean the skin using soap and water or hand sanitizer.
If irritation or redness occurs, seek medical attention.
Wash contaminated clothing before reuse.
If the product is injected into the skin or other body parts, contact a doctor immediately

Figure 9. MSDS example of B30

2.5. Determination of Criticality Level

The purpose of determining the critical level is to determine the priority level of the equipment or components in the RV. Baruna Jaya based on the level of risk. Risk results from the multiplication between the probability of failure and the level of consequences [11]. So, from each rating classification of the failure rate and the level of consequences, it will form a risk matrix. Several references according to standards, such as API, ABS, Norsok, etc., can be used to determine this level of risk. The institution risk matrix will be more accurate because the acceptable risk area is the company's ability to manage risk. However, the Institution risk matrix was not yet available during this analysis. Because the institution does not yet have a risk matrix, this analysis will reference the risk matrix on the existing standard. In the 2017 version of the Norsok Z-008 standard, the criticality is determined by the redundancy and consequence of the equipment [8], while in the 2011 version of the Norsok Z-008, there is a risk matrix that includes the parameters of probability and consequence. In this analysis, the risk matrix will reference the 2011 version of the Norsok Z-008 risk matrix. Figure 10 is a reference to the risk matrix taken from the 2011 version of the Norsok Z-008.

Probability				
	F4	M	H	H
	F3	M	M	H
	F2	L	M	H
	F1	L	L	M
		C1	C2	C3
			Consequence	

Figure 10. Risk matrix basd on Norsok Z-008 2011 [11]

2.6. Determination of Maintenance Strategy

After the maintenance of objects based on critical categories is obtained, the next step is determining the right maintenance strategy based on the critical level. In general, from the point of view of maintenance work, it is categorized in 2 (two) ways: Planned Maintenance and Unplanned Maintenance. Planned maintenance is an action or maintenance activity whose implementation has been planned. Unplanned maintenance is an action or maintenance activity whose implementation is not planned [15].

2.6.1. Planned Maintenance

Planned Maintenance is classified into two types:

a) Preventive maintenance. Defined as a scheduled maintenance system of an equipment/component designed to increase machine reliability and anticipate unplanned maintenance activities. Preventive maintenance is divided into:
- Time-based maintenance. This maintenance activity is based on a period including daily inspection, service, cleaning, and so on.
- Condition-based maintenance. This maintenance activity uses equipment to diagnose changes in the condition of equipment or assets and to predict the initial determination of maintenance time intervals.

b) Predictive maintenance. It is defined as a measurement that can detect system degradation so that the cause can be eliminated or controlled depending on the physical condition of the component. The results are indicative of current and future functional capabilities.

2.6.2. Unplanned Maintenance

Unplanned Maintenance is classified into two types.

a) Corrective maintenance. Defined as a maintenance activity carried out to repair and improve the machine's condition so that it reaches the standard set for the machine.

b) Breakdown maintenance. It is defined as a maintenance activity whose implementation waits until the equipment is damaged and repaired. This method is carried out if the failure effect is insignificant to operations or production.

Based on this maintenance strategy, equipment and components included in the high or medium-critical category will be carried out as planned maintenance. In contrast, equipment and components included in the low-level critical category will be carried out as an unplanned maintenance strategy.

3. Results and Discussion

3.1. Asset Hierarchy

To get the critical level of all assets, all assets must first be identified into a hierarchy and registered the assets. This hierarchy classification will start from the Plant, System, Sub Function, and Component Tag levels. In addition, asset data collection or registration will be carried out by providing a code according to its level. The code will stand in the order of System, Equipment, Sub Function, and Component. Table 10 shows the ship's system to be analyzed and its code. Figure 11 is a hierarchy of a freshwater cooling system and its code. Table 11 shows the freshwater cooling system's level 5 (Component tag). From the classification according to the hierarchy that has been made, the total number of existing assets from 6 systems is 766 consisting of 38 rotary equipment, 45 static equipment, 196 piping equipment, and 487 instrument equipment. Figure 12 shows the total assets, including equipment and components of the machinery system, according to the scope system in table 9.

Table 10. the scope of the system to be analyzed

No	System Name	System ID
1	Propulsion System	PPS
2	Fresh Water Cooling System	FCS
3	Sea Water Cooling System	SCS

4	Fuel Oil System	FOS
5	Lubricating Oil System	LOS
6	Air Compressed System	ACS

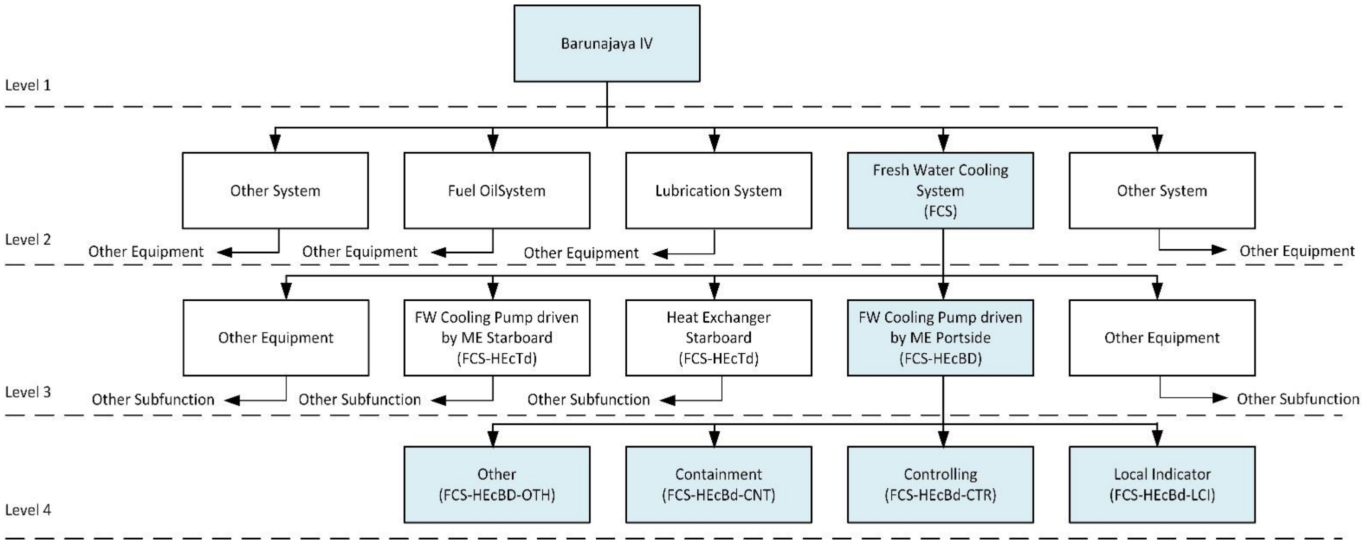

Figure 11. The hierarchy of the freshwater cooling system

Table 11. Detailed component Tag (level 5) on the freshwater cooling system

Sub Function ID (Level 4)	Sub Function Name	Component Tag (Level 5)	Component Name
FCS-HEcBd-CNT	Containment	FCS-HEcBd-CNT-412	ME Fresh Water Outet SB
FCS-HEcBd-CNT	Containment	FCS-HEcBd-CNT-414	ME Fresh Water Cooler Alimentation SB
FCS-HEcBd-CTR	Controlling	FCS-HEcBd-CTR-VO404-1	Valve Isolation Fresh Water Exchanger
FCS-HEcBd-LCI	Local Indicator	FCS-HEcBd-LCI-Th408-1	Thermometer
FCS-HEcBd-LCI	Local Indicator	FCS-HEcBd-LCI-Th408-2	Thermometer
FCS-HEcBD-OTH	Others	FCS-HEcBD-OTH-Fl412-3	Flexible on HE Piping

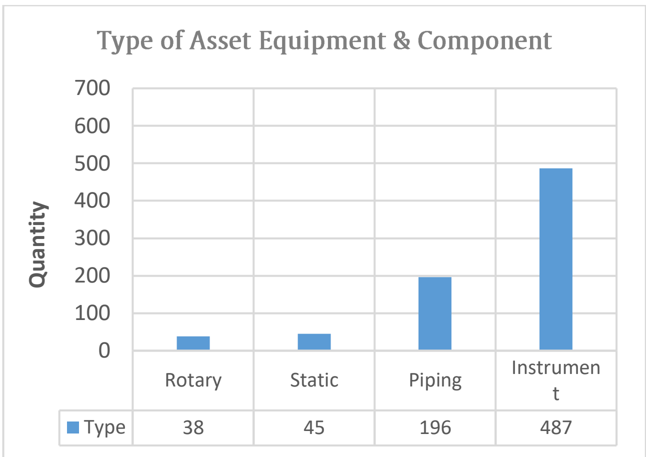

Figure 12. Total assets by type of equipment or components

3.2. Probability Rating

After all equipment and components are identified, the probability rating of failure must be determined to get the risk of equipment or components. This risk measurement will determine the critical level of the RV. Baruna Jaya' s maintenance object. The equipment's MTBF value in each system's scope is analyzed from the failure data obtained during two voyages. The overall operating time is taken for two voyages. The First voyage is 25 days (Feb-Mar period), and the second is 13 days (Oct period). So, the total operation is 38 days or 54720 minutes. Table 12 below shows the MTBF value from failure data for two voyages, obtained 9 data on equipment failure according to the scope of the analysis. To obtain failure data on other equipment, it is determined using the failure reference data from OREDA. Table 13 shows an example of 9 pieces of equipment from a total of 757 pieces of equipment that do not have historical failure data. The MTBF calculation is carried out using OREDA data.

Table 12. MTBF calculation from failure data

No	Equipment	Frequency of failure	Time to repair (minutes)	Uptime	Failure Rate (minutes)	MTBF (minutes)	MTBF (year)
1	Main Engine PS (PPS-A1Bd)	2	60	54660	3,65898E-05	27330	0,0520
2	Main Engine SB (PPS-A1Td)	1	5760	48960	2,04248E-05	48960	0,0932
3	Tube Heat Exchanger GB PS (SCS-R3)	1	30	54690	1,82849E-05	54690	0,1041
4	FW Pump Driven by ME PS (FCS-FPBd)	2	120	54600	3,663E-05	27300	0,0519
5	FW Pump Driven by ME SB (FCS-FPTd)	1	60	54660	1,82949E-05	54660	0,1040
6	Fresh Water Piping FW (FCS-HEcBd-CNT-412)	1	30	54690	1,82849E-05	54690	0,1041
7	SW Pump Driven by ME SB (SCS-SPTd)	2	240	54480	3,67107E-05	27240	0,0518
8	Heat Exchanger (Cental Cooler) FW SW PS (FCS-HEcBd)	1	30	54690	1,82849E-05	54690	0,1041
9	Heat Exchanger (Cental Cooler) FW SW SB (FCS-HEcTd)	1	30	54690	1,82849E-05	54690	0,1041

Table 13. Example of calculating MTBF from OREDA data

No	Equipment	Failure Mode Selected	Failure Rate 1	Failure Rate 2	Total Failure Rate	MTBF (year)
1	Feed Pump FO Portside (FOS-A7Bd)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
2	Feed Pump FO Starboard (FOS-A7Td)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
3	Fuel Oil Transfer Pump (FOS-M1)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
4	Lubricating Oil Pump Portside (LOS-A9Bd)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
5	Lubricating Oil Pump Starboard (LOS-A9Td)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
6	Thrust Block Lubricating Oil Pump Portside (LOS-Q13Bd)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
7	Thrust Block Lubricating Oil Pump Starboard (LOS-Q13Td)	1. External Leakage - Process Medium 2. Vibration	66,25	7,18	0,64	1,55
8	Main Air Compressor (ACS-K1)	1. Structural deficiency 2. Low output	4,8	202,49	1,82	0,55
9	Emergency Main Air Compressor (ACS-K2)	1. Structural deficiency 2. Low output	4,8	202,49	1,82	0,55

From the calculation above, it is then mapped according to Table 5 to get the probability of failure. The following Table 14 is an example of the probability of failure of the equipment that has been calculated MTBF in Tables 12 and 13. From the total of 766 existing equipment and components, based on the probability of failure F4 (Probable), F3 (Possible), F2 (Unlikely), and F1 (Rare), it is obtained that 11 (1%) equipment or components are at the F4 level, 18 (2%) are at the F3 level, 148 (20%) are at the F2 level, and 589 (77%) are at the F1 level. Figure 13 shows a graph of the equipment based on mapping the probability of failure according to F4, F3, F2, and F1.

Table 14. Value of the failure probability of some equipment

No	Equipment	MTBF (year)	Probability Rating	Equipment	MTBF (year)	Probability Rating
1	Main Engine PS (PPS-A1Bd)	0,0520	F4	Feed Pump FO Portside (FOS-A7Bd)	1,55	F3
2	Main Engine SB (PPS-A1Td)	0,0932	F4	Feed Pump FO Starboard (FOS-A7Td)	1,55	F3
3	Tube Heat Exchanger GB PS (SCS-R3)	0,1041	F4	Fuel Oil Transfer Pump (FOS-M1)	1,55	F3

4	FW Pump Driven by ME PS (FCS-FPBd)	0,0519	F4	Lubricating Oil Pump Portside (LOS-A9Bd)	1,55	F3
5	FW Pump Driven by ME SB (FCS-FPTd)	0,1040	F4	Lubricating Oil Pump Starboard (LOS-A9Td)	1,55	F3
6	Fresh Water Piping FW (FCS-HEcBd-CNT-412)	0,1041	F4	Thrust Block Lubricating Oil Pump Portside (LOS-Q13Bd)	1,55	F3
7	SW Pump Driven by ME SB (SCS-SPTd)	0,0518	F4	Thrust Block Lubricating Oil Pump Starboard (LOS-Q13Td)	1,55	F3
8	Heat Exchanger (Cental Cooler) FW SW PS (FCS-HEcBd)	0,1041	F4	Main Air Compressor (ACS-K1)	0,55	F4
9	Heat Exchanger (Cental Cooler) FW SW SB (FCS-HEcTd)	0,1041	F4	Emergency Main Air Compressor (ACS-K2)	0,55	F4

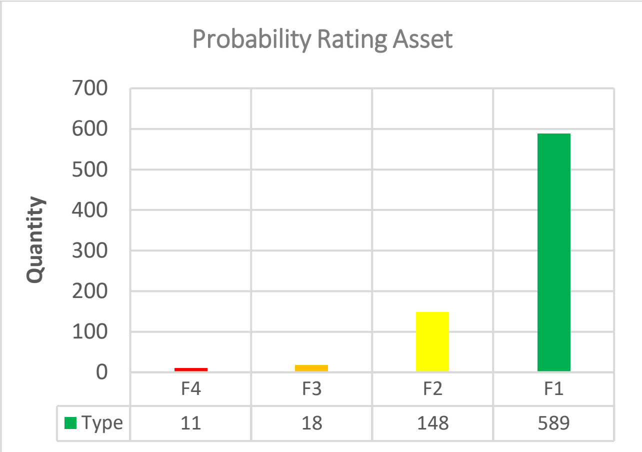

Figure 13. Probability rating chart

From the graph in Figure 13, the results are obtained from several levels of probability of failure from a total of 766 pieces of equipment and components. Institutions will tolerate equipment and components with categories below F2 (unlikely) on this graph. So level F1, F2, and F3 will get more attention when it is assigned to the maintenance object at RV. Baruna Jaya. Because at that level, the probability of equipment and component failure is included in the high and medium categories. At the F1 level, the probability of equipment and component failure will be considered afterward. The results of this probability level of failure will be combined again with the results of the level of consequences to consider how severe the impact will be if the equipment or component fails. And from this combination, the level of criticality based on risk will be obtained.

3.3. Consequence Rating

The consequence rating of failure must be determined to get the risk of equipment or components. This risk measurement will determine the critical level of the RV. Baruna Jaya' s maintenance object. The fluid data in the system needs to be known in advance to make it easier to conduct a consequence-level analysis. The following Table 15 shows the estimation of the fluid contained within the scope of the system being analyzed. From the fluid estimation, look for the fluid's characteristics in the Material Safety Data Sheet (MSDS) data. The following Table 16 is an example of the characteristics of the B30 fuel fluid. After obtaining fluid characteristic data, the next step is to map the possible consequences according to Tables 6, 7, 8, and 9. The following Table 17 results from mapping from the Portside FO Feed Pump equipment with the highest consequence value, namely the C3 value.

Table 15. Estimation of the fluid contained in the system

No	System Name	Estimation of Fluida inside the system
1	Propulsion System	B30, LO40, LO30, Fresh Water, Sea Water, Air
2	Fresh Water Cooling System	Fresh Water
3	Sea Water Cooling System	Sea Water
4	Fuel Oil System	B30
5	Lubricating Oil System	Shell Gardenia 40
6	Air Compressed System	Air

Table 16. B30 fuel fluid characteristics

Fluid Name	Composition	Health and Safety	Flammability	Toxicity	Pollution
Biodiesel B30	Hydrocarbons, fraction	Aspiration hazard, skin	Flammable liquid and vapor	Acute toxicology showed no acute	Seepage into the ground will cause

	diesel, Distilled, C8-C2h6 forked and straight Kerosene, C8-C16 branched and straight alkanes, FAME	corrosion/irritation, acute toxicity, inhalation, carcinogenesis	(Flashpoint 125 F or 52 C)	effect through breathing when tested using mist.	groundwater or aquifer contamination.

Table 17. Determination of consequence level of FO Portside Feed Pump

Equipment	Health and Safety	Containment	Pollution	Production
Feed Pump FO Portside (FOS-A7Bd)	(C2) Potential for injuries requiring medical treatment, Limited effect on safety systems	(C2) Flammable media below flashpoint, Moderately toxic media, High pressure/temperature media (>100 bar/80 °C)	(C2) Potential for moderate pollution.	(C3) Immediate and significant loss of production

Of the total 766 existing equipment and components, overall based on the C3 (Critical), C2 (Serious), and C1 (Minor) levels, 31 (4%) equipment or components were at the C3 level, 459 (60%) were at the C2 level, and 276 (36%) were at the C1 level. Figure 14 below is a graph of the equipment based on the mapping of consequences levels according to C3, C2, and C1

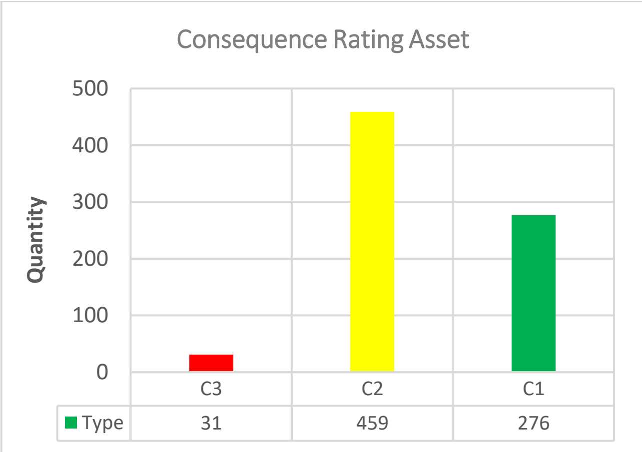

Figure 14. Consequence rating chart

The graph in Figure 14 shows the results of several failure consequences from 766 equipment and components. Institutions will tolerate equipment and components under category C2 (serious) on this chart. So, levels C3 and C2 will receive more attention when used as maintenance objects in RV. Baruna Jaya. Because at that level, equipment and component failure consequences are included in the high and medium categories. At level C1, the consequences of the failure of equipment and components will be considered afterward. The results of this failure consequence level will be combined again with the results of the probability level to consider how often the equipment or component fails. And from this combination, the criticality level based on risk will be obtained.

3.4. Criticality Level

Risk determination is done by mapping the level of failure and consequences into the risk matrix. Using the risk matrix according to Figure 10, the data on the probability of failure and the level of consequences obtained are then determined by the risk value of the equipment. Of the 766 equipment and components analyzed, 23 (3%) were found in H (high), 138 (18%) in M (medium), and 605 (79%) in L (low). Figure 15 below is a graph of equipment criticality based on H (High), M (Medium), and L (Low) levels. Table 18 shows 23 equipment and components with a high critical level. Table 19 shows the number of equipment and components in each system according to their criticality level. In Pareto' s theory, a plant is supported by approximately 20% of critical equipment.

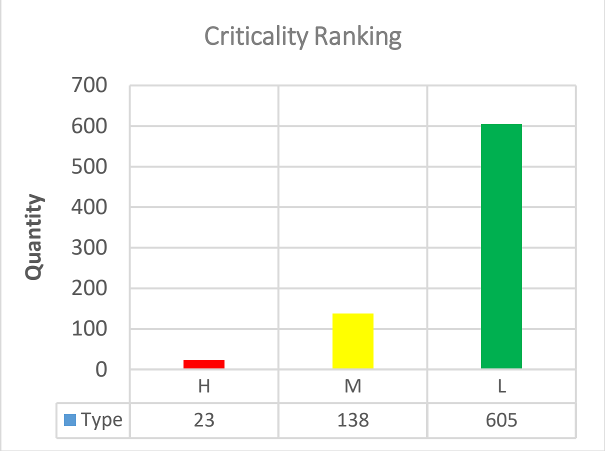

Figure 15. Critical level chart

From the graph in Figure 14, the results are obtained from the criticality level of 766 equipment and components. Institutions will tolerate equipment and components with a critical level under category M (Medium) on the chart. So, H and M levels will be given more attention when used as maintenance objects in RVs. Baruna Jaya. Because at that level, failures and consequences of equipment and components are included in the high and medium categories. At the C1 level, the critical level of equipment and components will be considered later. Based on the Pareto principle, equipment with critical levels H and M fall into the critical category. Table 20 shows the number of critical percentages, as much as 21%, based on Pareto.

Table 18. equipment and components with a critical level of High (H)

No	Item Name	P	C	R	No	Item Name	P	C	R
1	Main Engine Portside (PPS-A1Bd)	F4	C3	H	13	Thrust Block Lubricating Oil Pump Portside (LOS-Q13Bd)	F3	C3	H
2	Main Engine Starboard (PPS-A1Td)	F4	C3	H	14	Thrust Block Lubricating Oil Pump Starboard (LOS-Q13Td)	F3	C3	H
3	Gearbox (PPS-Gb)	F3	C3	H	15	Heat Exchanger Portside (FCS-HecBd)	F4	C2	H
4	Controllable Pitch Propeller (PPS-CPP)	F3	C3	H	16	Heat Exchanger Starboard (FCS-HecTd)	F4	C2	H
5	Feed Pump FO Portside (FOS-A7Bd)	F3	C3	H	17	FW Cooling Pump is driven by ME Portside (FCS-FPBd)	F4	C3	H
6	Feed Pump FO Starboard (FOS-A7Td)	F3	C3	H	18	FW Cooling Pump is driven by ME Starboard (FCS-FPTd)	F4	C3	H
7	Fuel Oil Transfer Pump (FOS-M1)	F3	C3	H	19	SW Cooling Pump is driven by ME Starboard (SCS-SPTd)	F4	C3	H
8	Lubricating Oil Pump Portside (LOS-A9Bd)	F3	C3	H	20	Tube Heat Exchanger GB Portside (SCS-R3)	F4	C2	H
9	Lubricating Oil Pump Starboard (LOS-A9Td)	F3	C3	H	21	Main Air Compressor (ACS-K1)	F4	C3	H
10	Reduction Gear Lubricating Oil Pump Portside (LOS-B3Bd)	F3	C3	H	22	Emergency Main Air Compressor (ACS-K2)	F4	C3	H
11	Engine Lubricating Oil Stand by Pump Starboard (LOS-N1Td)	F3	C3	H	23	Emergency Air Compressor (ACS-K13)	F4	C3	H
12	Reduction Gear Lubricating Oil Stand by Pump (LOS-N2)	F3	C3	H					

Table 19. The number of equipment in each system according to the level of criticality

No	System Name	H	M	L
1	Propulsion System	4	0	0
2	Fresh Water Cooling System	5	5	38
3	Sea Water Cooling System	1	4	197
4	Fuel Oil System	3	30	152
5	Lubricating Oil System	7	50	140
6	Air Compressed System	3	49	78

Table 20. criticality to pareto conversion

Category	Jumlah	Presentase	Pareto
H	23	3%	21%
M	138	18%	
L	605	79%	79%

3.5. Maintenance Strategy

From the criticality level obtained from 766 equipment and components analyzed, 23 (3%) of equipment in H (high) condition and 138 (18%) in M (medium) condition will be carried out planned maintenance which includes Preventive maintenance (Time based maintenance/Condition-based maintenance) and Predictive maintenance. Meanwhile, 605 (79%) of equipment in L (low) condition will be carried out unplanned maintenance, including corrective maintenance and breakdown maintenance.

4. Conclusion

This research aims to determine the maintenance object of the RV. Baruna Jaya is based on its critical level. By classifying all assets into a hierarchical form and performing a risk-based criticality analysis, equipment will be prioritized based on its risk from the probability of failure and the level of consequence. From the analysis that has been carried out on the Baruna Jaya Research vessel with the scope of the propulsion system (PPS), fresh water cooling system (FCS), seawater cooling system (SCS), fuel system (FOS), lubrication system (LOS), and system compressed air (AVS) obtained equipment and components with a total of 766 with 38 rotary type equipment, 45 static types, 196 piping type, and 487 instrument type. From determining the failure rate of equipment or components, 11 (1%) of equipment or components are at the F4 level, 18 (2%) are at the F3 level, 148 (20%) are at the F2 level, and 589 (77%) are at the F2 level. F1 level. Meanwhile, from determining the level of consequences, 31 (4%) of equipment or components are at the C3 level, 459 (60%) are at the C2 level, and 276 (36%) are at the C1 level. So from 766 equipment and components that were carried out criticality analysis, 23 (3%) of equipment was found in H (high), 138 (18%) in M (medium), and 605 (79%) in L (low) conditions. From the criticality level obtained, equipment that is in H (high) and M (medium) conditions will be carried out planned maintenance which includes Preventive maintenance (Time based maintenance/Condition-based maintenance) and Predictive maintenance. Meanwhile, equipment in L (low) condition will be subjected to unplanned maintenance, including corrective and breakdown maintenance.

After all the methodologies and results are obtained, it can be developed for further research in the object maintenance database. The database can be developed into a DSS (Decision Support System) software with input in the form of real-time component failure records. This failure data will continue to change with age and maintenance activities carried out on equipment or components so that the criticality level of an equipment or component can also change according to its probability level.

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