BACHELOR THESIS & COLLOQUIUM – ME234804

SHIP MAINTENANCE STRATEGY USING THE RELIABILITY CENTERED MAINTENANCE METHOD, CASE STUDY: COMPRESSED AIR SYSTEM AND COOLING SYSTEM IN RO-RO PASSENGER SHIP

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DOUBLE DEGREE PROGRAM

DEPARTMENT OF MARINE ENGINEERING

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Submitted to Fulfill One of The Requirements
For obtaining a bachelor's degree in engineering at
Undergraduate Study Program of Marine Engineering
Department of Marine Engineering
Faculty of Marine Technology
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By: **FLADDY SAMUDRA BAKTI**

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Date	:	2, August 2024

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AUGUST, 2024

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STATEMENT OF ORIGINALITY

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Hereby declare that the Final Project with the title of **"SHIP MAINTENANCE STRATEGY USING THE RELIABILITY CENTERED MAINTENANCE METHOD, CASE STUDY: COMPRESSED AIR SYSTEM AND COOLING SYSTEM IN RO-RO PASSENGER SHIP"** is the result of my own work, is original, and is written by following the rules of scientific writing.

If in the future there is a discrepancy with this statement, then I am willing to accept sanctions in accordance with the provisions that apply at Institut Teknologi Sepuluh Nopember.

Surabaya, 2 August 2024

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ABSTRACT

SHIP MAINTENANCE STRATEGY USING THE RELIABILITY CENTERED MAINTENANCE METHOD, CASE STUDY: COMPRESSED AIR SYSTEM AND COOLING SYSTEM IN RO-RO PASSENGER SHIP

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Supervisor 1	**: Hari Prastowo, M.Sc**
Supervisor 2	**: Dr. Nurhadi Siswantoro, S.T., M.T.**

Abstract

In 2014, PT. X launched KMP. X, the largest RoRo ferry in Indonesia, with a deadweight of 5,000 GT and a length of 109.40 meters, connecting Surabaya to Lombok. To ensure operational reliability, this study analyzes the failure mode of components and their impact on both the compressed air and cooling systems, assesses the criticality of each component within these systems, and evaluates maintenance strategies and work packages for these components. This study applies a Reliability Centered Maintenance (RCM) approach to the cooling system and compressed air system, utilizing repair history data from 2015 to 2024. The analysis reveals that for the cooling system, Category A includes 21 task lists, Category B includes 23 task lists, and Category C includes 4 task lists, totaling 48 tasks which consist of Preventive Maintenance (PM) at 17% (8 tasks), Condition Monitoring (CM) at 17% (8 tasks), a combination of Corrective Maintenance and Planned Maintenance (CM/PM) at 42% (20 tasks), Other Tasks (OTC) at 4%, and Failure Finding (FF) at 21%. For the compressed air system, there are 36 tasks distributed as Preventive Maintenance (PM) at 38% (13 tasks), Condition Monitoring (CM) at 9% (3 tasks), a combination of CM/PM at 35% (12 tasks), with OTC and FF each at 9% (3 tasks). The CM/PM combination approach is dominant in both systems, highlighting the importance of integrated preventive and corrective actions in ensuring operational reliability and effective system maintenance

Keywords: Cooling System, Compressed Air System, FMECA, RCM

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ABSTRAK

STRATEGI PERAWATAN KAPAL DENGAN MENGGUNAKAN METODE RELIABILITY CENTERED MAINTENANCE, STUDI KASUS SISTEM UDARA TERKOMPRESI DAN SISTEM PENDINGIN PADA KAPAL PENUMPANG RO-RO

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Abstrak

Pada tahun 2014, PT. X meluncurkan KMP. X, kapal feri RoRo terbesar di Indonesia, dengan bobot mati 5.000 GT dan panjang 109,40 meter, yang menghubungkan Surabaya ke Lombok. Untuk memastikan keandalan operasional, tugas akhir ini menganalisis mode kegagalan komponen dan dampaknya terhadap sistem udara terkompresi dan sistem pendingin dengan menilai kekritisan setiap komponen dalam sistem ini dan mengevaluasi strategi perawatan untuk komponen-komponen tersebut. Tugas akhir menerapkan pendekatan Reliability Centered Maintenance (RCM) pada sistem pendingin dan sistem udara terkompresi, dengan menggunakan data riwayat perbaikan dari tahun 2015 hingga 2024. Hasil analisis menunjukkan bahwa untuk sistem pendingin, Kategori A mencakup 21 daftar tugas, Kategori B mencakup 23 daftar tugas, dan Kategori C mencakup 4 daftar tugas, dengan total 48 tugas yang terdiri dari Preventive Maintenance (PM) sebesar 17% (8 tugas), Condition Monitoring (CM) sebesar 17% (8 tugas), kombinasi dari Corrective Maintenance dan Planned Maintenance (CM/PM) sebesar 42% (20 tugas), Tugas Lainnya (OTC) sebesar 4%, dan Failure Finding (FF) sebesar 21%. Untuk sistem udara terkompresi, terdapat 36 tugas yang didistribusikan sebagai Preventive Maintenance (PM) sebesar 38% (13 tugas), Condition Monitoring (CM) sebesar 9% (3 tugas), kombinasi CM/PM sebesar 35% (12 tugas), dengan OTC dan FF masing-masing sebesar 9% (3 tugas). Pendekatan kombinasi CM/PM sangat dominan di kedua sistem, menyoroti pentingnya tindakan pencegahan dan perbaikan terintegrasi dalam memastikan keandalan operasional dan pemeliharaan sistem yang efektif.

Kata kunci: FMECA, RCM, Sistem Pendingin, Sistem Udara Terkompresi

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This bachelor thesis is a culmination of countless hours of dedication, support, and collaboration. Author humbled and honored to have had the opportunity to work on this project. May this thesis contribute positively to the field of study and serve as a testament to the power of collective effort and unwavering determination.

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CHAPTER 1

INTRODUCTION

1.1 Research Background

In recent years, recent phenomena in the maritime industry have recorded a significant increase in efforts to improve the sustainability and operational efficiency of ships. This development is reflected in increasing awareness of the environmental impacts of ship operations, which has led to the identification of risks and potential improvements. An integrated risk management system is an important part of a sustainability strategy, ensuring that ships are not only environmentally efficient but can also identify manage and mitigate risks effectively during their operations. Collaboration between industry, government, and research institutions is also needed to design better guidelines and standards to mitigate risks that may arise on the journey towards more sustainable ship operations. The next step is to develop a strategy to manage the identified risks. This includes risk mapping, selecting steps or handling strategies for each risk, as well as determining response actions to existing risks.

PT. X Indonesia Ferry (Persero) is a state owned firm that provides integrated ferry and port services, as well as waterfront tourism destinations. PT. X manages a ferry fleet of over 226 vessels, serving 307 routes and 36 ports around Indonesia, as well as other port development enterprises such as Bakauheni Harbor City in Lampung Province and the Labuan Bajo Marina Area in East Nusa Tenggara. In 2014, PT. X launched its biggest ferry, KMP. X on the LDF route connecting Surabaya to Selamat Harbor in Lombok, West Nusa Tenggara. KMP. X is the largest RoRo (Roll on Roll off) ferry in Indonesia, with a displacement of 5,000 Gross Tonnage (GT) and a length of 109.40 meters.

Figure 1. 1 Business Data Distribution of PT. X

(Source : PT.PT. X.com)

The presence of KMP. X demonstrates that shipping is a widely used and crucial mode of transportation for sustaining global trade. However, because of the nature of the marine environment, the maritime industry and related operations represent a complicated and dangerous work environment (Mallam et al., 2022). As a result, the International Maritime Organization (IMO), which establishes standards for environmental performance, safety, and security in international shipping notes both the industry's popularity and potential hazards and difficulties. Globally, new laws are always being enacted to eradicate maritime hazards, and flag and port state controls tightly regulate these laws. Every year, devastating ship catastrophes happen despite the tight laws, standardized regulations, and advancements in engineering and technology (Fan et al., 2022). An examination of functional breakdowns from 2015 to 2024 reveals that propulsion systems have been most affected. Specifically, out of 42 total failures, 14 were identified within the main engine support systems.

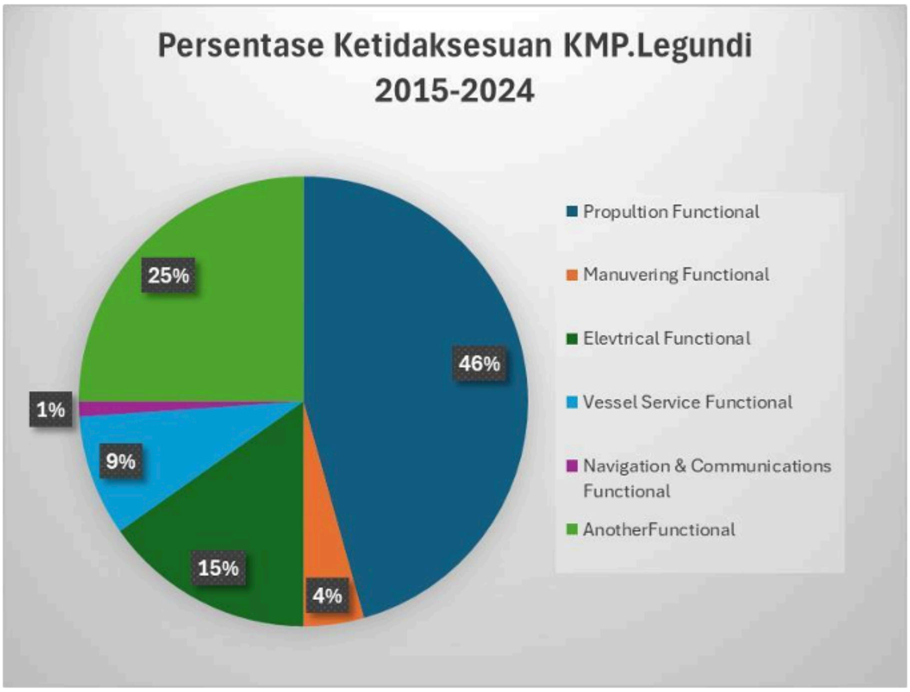

Figure 1. 2 Percentage of nonconformities in KMP.X

(Source : PT.PT. X.com)

According to the 2021 summary of marine casualties and events, loss of control and propulsion power was the most common occurrence. Furthermore, if the ship loses propulsion power, more worse disasters such as grounding, contact, and collision may occur. On the other hand, the ship's loss of propulsion power is directly related to its main engine and auxiliary engine. Ship engine rooms are intricate technical constructions that house equipment such as a boiler, separator, generator, evaporator, main engine, steam, and compressed air (Ceylan et al., 2022). Ferries need to be built with excellent comfort and stability, as well as outstanding operational and financial features, in order for them to operate at peak efficiency. As a result, the ship requires a propulsion system, often known as a drive system. Diesel Mechanical Propulsion is the primary driving motor for the propulsion system on nearly all of PT Ferry Ro-Ro's ship fleet (Agustian & Fathallah,.d.).

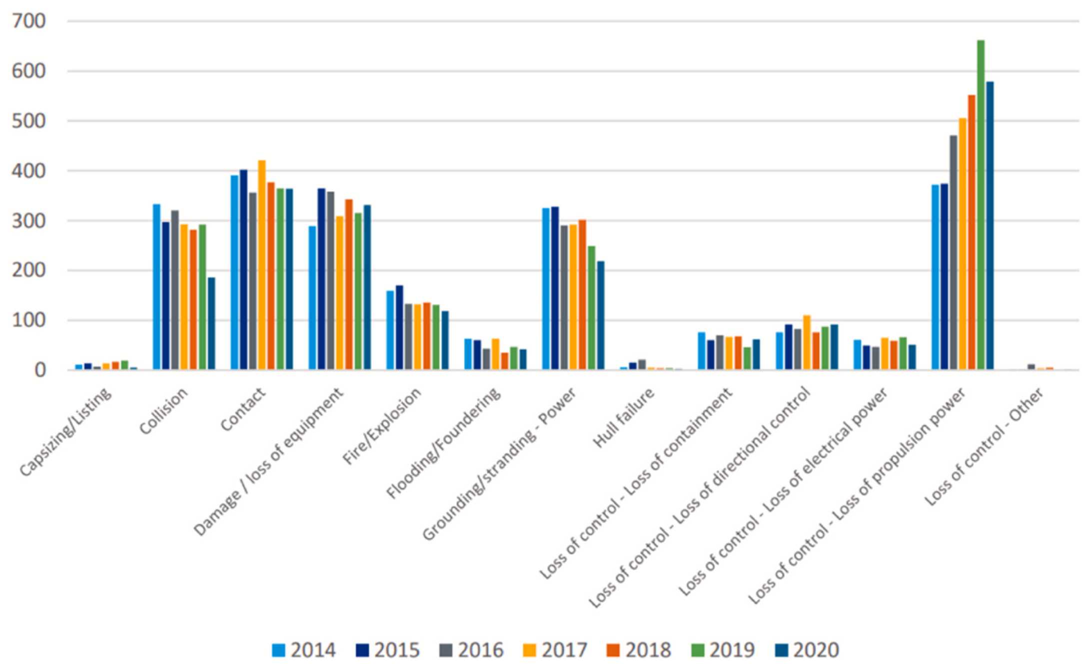

Figure 1. 3 Distribution of ship casualty events between 2014 and 2020 (EMSA, 2021)

The compressed air system and cooling system stands out since it directly powers the ship's main engine and diesel generators during startup and during ordinary operation. Parts of the engine are cooled by the cooling system. Through engine jacket ducts, this procedure involves cooling the engine block, the combustion chamber, and the lubricating fluid. According to Kara, Sitepu, et al. (2023), the compressed air system, functioning as a compressed air generator, plays a vital function in supplying air for the primary engine's first start-up as well as auxiliary engines and operational air services in the engine and ship deck.

Safety at sea is one of the most important concerns in the maritime industry as it can have terrible consequences for property, the environment, and human life. This is due of the possibility that damage to one of these systems could affect the main engine's overall performance. A single system or component failure might result in more failures and losses. Analyzing the system's or component's failure risk is therefore essential. Failure and repair procedures are essential components in any endeavor to forecast a system's future and the potential effects that an operational failure of one component may have on other components (Danil Arifin et al., 2020). Every significant piece of equipment or component in the primary engine support system needs to have a maintenance strategy implemented in order for it to continue functioning at its best.

An asset or system's maintenance activities are required since maintenance is the primary task for every significant asset or complex system, particularly those that pose a risk to the environment and public safety, such shipboard systems (Deris, 1999). Corrective and preventative maintenance are the two primary categories of maintenance. Similar to repair, corrective maintenance is carried out after damage has occurred or when failure is clearly visible. Optimal corrective maintenance, however, is limited to non-critical sectors where costs are low, failure consequences are negligible, safety risks and repercussions are low, and failures can be swiftly identified and repaired.

Risk analysis studies are crucial for the maritime industry in identifying risks and preventing their occurrence. In this sense, researchers used different techniques in recent years in the maritime field, such as Fault Tree Analysis (FTA), Event Tree Analysis (ETA), Bow-Tie Analysis, Risk Matrix, Formal Safety Assessment (FSA), Failure Mode and Effects Analysis (FMEA), Bayesian Network (BN), Analytic Hierarchy Process (AHP), Success Likelihood Index Method (SLIM), Cognitive Reliability and Error Analysis Method (CREAM), Human Factors Analysis and Classification System (HFACS), and Human Error Assessment and Reduction Technique (HEART). Among these methods that have been used frequently in recent years, FMEA has a strong capacity for dealing with engineering system failures and was chosen as a method for this study. However, there are some limitations of this method, as will be stated in the following parts of the study. For this reason, the FMEA approach which will be developed through reliability centered maintenance (RCM) method was employed in the analysis of compressor system and Cooling System risks in this study (Wang et al., 2021).

Therefore, a maintenance strategy is required to ensure the optimal functioning of the system and to prevent unwanted risks and outcomes. A potential solution is a risk-oriented maintenance strategy based on the concept of Reliability-Centered Maintenance (RCM). According to Moubray (1997), RCM analyzes the functionality of the system and its potential failures, identifies the consequences of these failures, and determines appropriate preventive actions using standardized logical procedures. The primary goal of RCM is to reduce maintenance costs by focusing on the critical functions of the system and eliminating or avoiding unnecessary maintenance actions. If a maintenance program already exists, the results of RCM analysis often eliminate inefficient preventive or maintenance actions.

The selection of KMP. X was based on its crucial role in supporting maritime connectivity in Indonesia. In facing society's demands for efficient and environmentally friendly transportation, KMP. X is a significant representative. By analyzing the risks in the compressed air system and cooling system on this ship, this research is expected to provide in depth insights and concrete solutions to improve the sustainability and operational efficiency of ships. This project intends to enhance the Reliability Centered Maintenance (RCM) method to be a more adaptable and efficient risk analysis tool. By exploring risks to the compressed air and cooling systems at KMP. X, this research seeks to provide an in depth understanding of operational complexity and uncertainty.

1.2 Problem Statement

Based on the background described above, the author formulates the problems that will be studied in this writing, as follows:

1. How to analyze the failure mode of a component and its impact on the compressed air system and cooling system?
2. How to analyze the criticality of a component in a compressed air system and cooling system?
3. How to analyze a maintenance strategy and work package for components in the compressed air system and cooling system?

1.3 Research Objectives

To be able to realize the writing of this final project, it is necessary to limit the problem as follows:

1. To analyze the failure mode of a component and its impact on the compressed air system and cooling system.
2. To analyze the criticality of a component in a compressed air system and cooling system.
3. To analyze a maintenance strategy and work package for components in the compressed air system and cooling system.

1.4 Scope of Research

Based on the discussion of the problems explained above, the aim of this research is:

1. The system components will be used in this research are the compressor system and cooling system.
2. The ship used in this research was a 5000 GT ferry KMP. X.
3. The basis of this research follows FMEA and Reliability Centered Maintenance ABS guidelines.

1.5 Research Benefit

The various benefits obtained from this final project research are divided into three, namely:

1. The research expected to contribute to the safety and reliability of ships.
2. The research expected to be a reference for other researchers if they want to research further regarding FMECA.
3. This research is expected to produce data regarding potential failures and their impact on the compressed air system and cooling system of KMP. X, as well as providing maintenance strategy recommendations to PT. X to improve the quality of shipping services.

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CHAPTER 2

LITERATURE REVIEW

2.1 State of the Art

Failure Mode and Effect Analysis (FMEA) is a systematic approach in the maritime sector for identifying potential failure modes, their effects, and the risks associated with those failures in marine systems and equipment. FMEA is a bottom-up analytical approach that reduces possible failures while improving safety, environmental performance, and operational downtime. ABS is a classification organization that gives recommendations on FMEA for marine systems with emphasizing the significance of conducting FMEAs early in the design process and adhering to standard qualitative analysis methodologies. The analysis should be thorough enough to establish conformity with the relevant criteria and it should adhere to normal qualitative analysis processes. FMEA is also used in risk based preventive maintenance planning. It synthesizes potential failure modes to identify and prioritize maintenance methods based on.risk levels (Cicek et al., 2010).

A study from (Zulfaidah Ariany et al.,2023) is utilizing instruments like the Probability Impact Matrix and Risk Priority Number (RPN) computation, the study offers an extensive framework for ranking mitigation measures according to risk levels. The results have implications for enhancing project viability, production procedures and stakeholder engagement since they highlight the need of proactive risk management in guaranteeing the security and accomplishment of high. value projects like shipbuilding.

(Efe, 2019) In this research is assessing risk in shipbuilding based on failure mode and effect analysis (FMEA). It solves the constraints of the classic FMEA technique by using quality function deployment (QFD) and VIKOR approaches, as well as intuitionistic numbers to handle the correlation between design requirements, customer requirements, and their relationship.

The research suggests failure modes, their causes, and effects are identified as part of the FMEA process after which each failure mode's criticality is assessed. Usually, a risk matrix that incorporates both the probability of occurrence and the seriousness of the effects is used for this assessment. FMEA data can be utilized to lower the risk of failures, enhance system design, and prioritize maintenance procedures (Siswantoro et al., 2020).

A study used a new decision-making method to investigate common defects in ship diesel generators. They discovered that the most common fault group is low power output, which is frequently caused by fuel system faults or a low engine speed. Sensor and instrument failures, especially at high temperatures, are also critical. The study emphasizes the necessity of maintaining ideal operating conditions, replacing worn parts, and assessing sensor data to avoid generator failures. (Yucesan et al., 2022)

The research suggests using Fault Tree Analysis (FFTA) from (TÖZ et al., 2022) to improve safety during ship mooring operations. By examining real-world cases, the study identified key events leading to accidents. Crew mistakes, especially related to watchkeeping and navigation regulations, were found to be more impactful than external factors. To enhance safety, the authors recommend regular crew proficiency assessments, training refreshers, strict lookout adherence, improved onboard communication, and fatigue management plans.

A study from (Kalghatgi, 2023) using big data tools in the maritime industry to make better decisions and work more efficiently. By using advanced technologies like IoT, Big Data, and AI, ship maintenance can be improved through Reliability Centered Maintenance (RCM). Data from ships, such as engine parameters and weather reports, can help enhance fleet performance. Integrating Big Data and AI is seen as a way to create a new maintenance model for growth in the shipping industry.

(Badrus et al., 2010) The study shows how important it is to maintain the cooling system of Tugboat Kresna 315 properly to avoid breakdowns. By following a planned maintenance schedule and having spare parts ready, the ship can operate smoothly and save costs. The cooling system is vital for preventing the engine from overheating during sea operations.

2.2 Compressed Air System

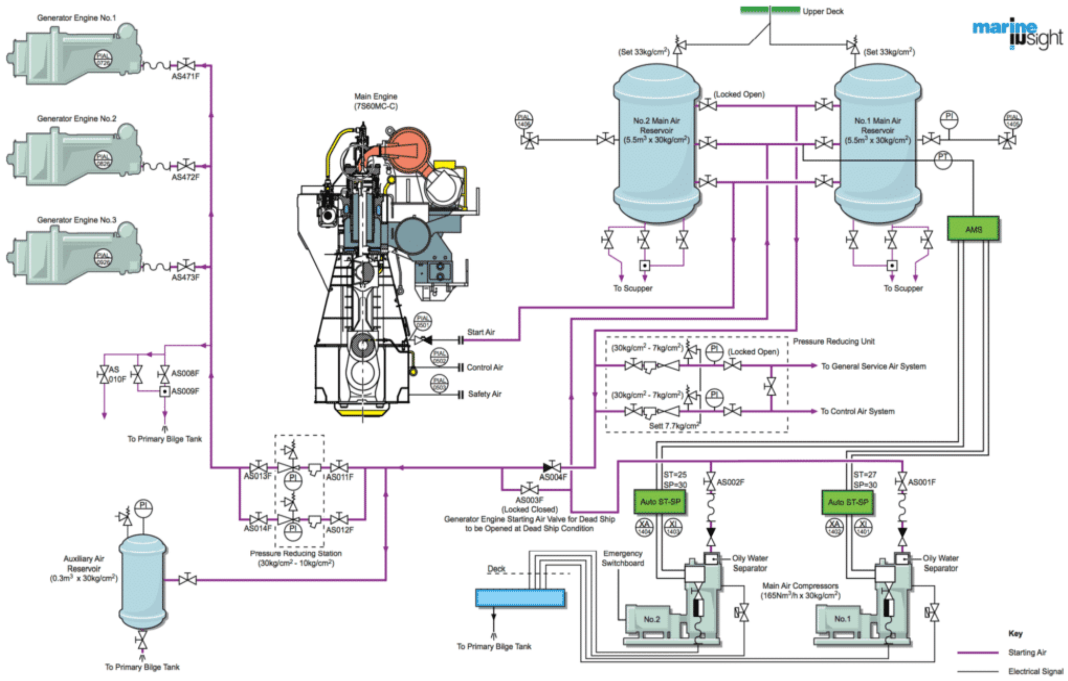

Figure 2. 1 Compressed Air System

(Source : marineinsight.com)

A compressed air system is a mechanical system that uses compressed air as the working fluid for several applications. A compressed air system usually includes an air compressor that increases the pressure of atmospheric air and a system of pipes, valves, filters, and other parts to transport the compressed air to its required destination. Compressed air systems are commonly utilized in diverse sectors and applications because of their benefits, including safety, cleanliness, flexibility, and the ample availability of air as a working medium (Kaya et al., 2022)

These systems are frequently utilized in manufacturing, process industries, maintenance industries, construction, mining, and maritime environments such as ships. The compressed air produced by the system has multiple applications such as powering pneumatic equipment, operating machines, starting engines, cleaning surfaces, and more. Choosing, using, and caring for the compressor and additional equipment are essential for the optimal performance of a compressed air system. Compressed air systems are crucial in several industrial operations, offering a flexible and dependable power source for a variety of jobs.

Compressed air systems offer benefits in safety, cleanliness, flexibility, and the availability of air as the working medium, its extensively utilized across industries such as manufacturing, process and maintenance, construction, mining, and maritime sectors. Air compressors are essential components of compressed air systems, used to increase air pressure either by reducing volume or by accelerating molecules. A compressed air system is a mechanical system that uses compressed air as a working substance for various purposes. It provides benefits such as safety, cleanliness, flexibility, and extensive availability in industries and maritime situations such as ships (Kaya et al., 2022).

The compressed air system consists of the following components:

1. Air Compressor

   Draws in ambient air and compresses it to a higher pressure for various applications on the ship.

2. Air Filter

   Filters out dust and impurities from the air before it enters the compressor to prevent damage to the compressor and system.

3. Air Receiver Tank

   Stores compressed air, stabilizes air pressure, and reduces pressure fluctuations in the system.

4. Air Dryer

   Removes moisture from the compressed air to prevent corrosion and damage to equipment using compressed air.

5. Pressure Regulator

   Regulates and maintains the appropriate air pressure for different applications on the ship.

6. Air Piping

   Distributes compressed air from the compressor to various points of use throughout the ship.

7. Safety Valve

   Releases excess pressure from the compressed air system to prevent explosions or damage to equipment.

8. Air Heater

   Heats compressed air for specific applications requiring hot air.

9. Lubricator

   Adds lubricant to the compressed air to lubricate pneumatic equipment and reduce friction and wear.

10. Pressure Gauge

   Measures and displays the air pressure within the system for proper monitoring and adjustment.

11. Shut-off Valve

   Stops the flow of compressed air to specific parts of the system for maintenance or repair.

12. Control and Automation System

   Controls the operation of the compressor and other components, ensuring the system runs automatically and efficiently.

2.3 Cooling System

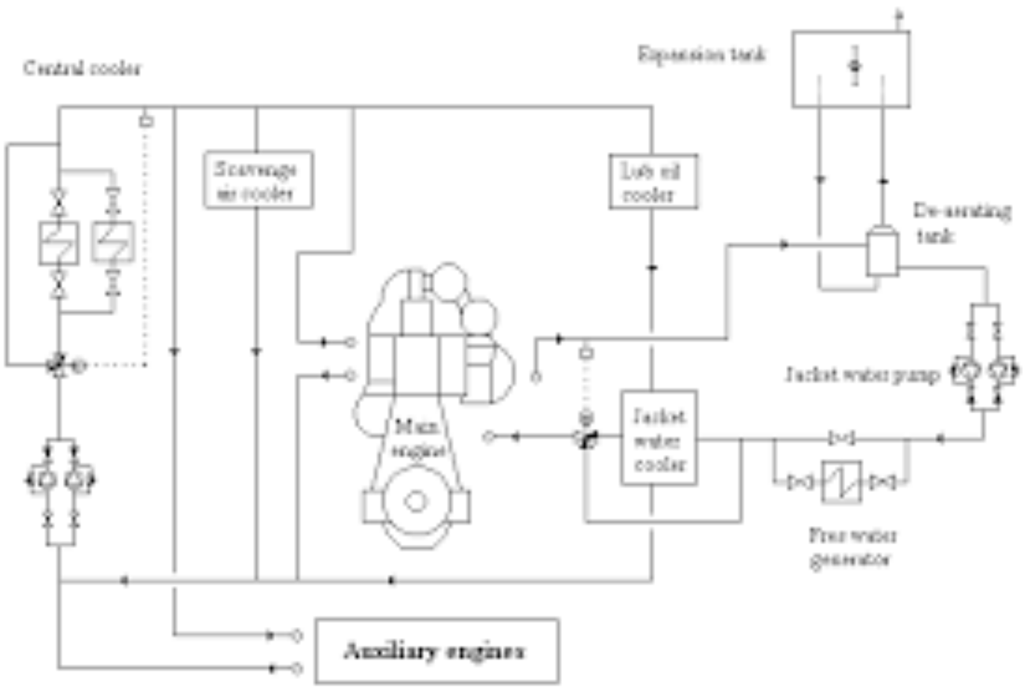

Figure 2. 2 Cooling System

(Source : i0.wp.com)

The ship's central cooling system handles the cooling of ME and auxiliary equipment. The system has two main streams: seawater and freshwater. The ME is cooled by the High

Temperature Fresh Water (HTFW) system, while the other auxiliary coolers are cooled by the Low Temperature Fresh Water (LTFW) system. The primary function of the cooling system is to dissipate the heat generated by the main engine (ME) and auxiliary equipment on the ship. This is essential for maintaining the components at optimal operating temperatures and preventing overheating (Yamin Yan. 2019).

The cooling system is responsible for controlling the temperature of critical components such as the ME, lubricating oil, Compressed Airs, turbochargers, and generators. By regulating the temperature, the system ensures efficient and safe operation of these components. Through load optimization and the use of variable speed pumps, the cooling system aims to reduce energy consumption during slow steaming operations. By adjusting the flow rates of sea water and fresh water based on the main engine load, energy savings can be achieved.

The cooling system can be integrated with waste heat recovery systems to capture and utilize excess heat for generating electrical power. This approach helps in reducing the overall energy demand of the ship's auxiliary machinery, contributing to energy savings and emission reductions. The cooling system is equipped with sensors and control mechanisms to monitor temperatures, flow rates, and other parameters in real-time. This allows for adjustments to optimize performance, enhance energy efficiency, and ensure safe operation of the equipment (Yamin Yan. 2019).

The cooling system consists of the following components:

1. Cooling Pump

   Circulates the cooling water throughout the entire cooling system, ensuring sufficient flow to absorb heat from the engine and other components.

2. Heat Exchanger

   Transfers heat from the engine's cooling water to seawater or other freshwater without mixing them. This helps cool the water that has absorbed heat from the engine.

3. Sea Chest

   Intakes seawater used in the cooling system. The sea chest is a box located below the ship's waterline that has filters to prevent debris from entering the cooling system.

4. Filter/Strainer

   Filters out debris and foreign particles from the cooling water before it enters the engine. This is crucial to prevent damage and blockages in the system.

5. Coolant Pump

   Specifically circulates coolant (usually a mixture of water and antifreeze) within the engine and radiator.

6. Thermostat

   Controls the flow of cooling water based on the engine temperature. If the engine is too hot, the thermostat opens to allow more cooling water flow. If it is too cold, the thermostat closes to reduce the flow.

7. Expansion Tank

   Provides space for the cooling water to expand when it heats up and prevents excessive pressure in the system. This tank also serves as a reservoir for extra cooling water.

8. Pipes and Hoses

   Carry cooling water between the various components of the cooling system. These pipes and hoses must withstand high pressure and temperature.

9. Radiator

   Cools the cooling water using air. Radiators are typically used in engine cooling systems that utilize freshwater as the cooling medium.

10. Bypass Valve

   Directs the flow of cooling water directly to the engine or other systems without passing through the heat exchanger under certain conditions, such as when the engine is still cold.

2.4 Ship Accidents

According to the Ministry of Transport of the Republic of Indonesia, general ship accidents in Indonesia have been a significant concern, with various types of incidents occurring across different maritime regions. These incidents encompass a range of accident types, the most common of which include sinking, collision, grounding, and fires. Among these, sinking is particularly prevalent, accounting for 31% of all incidents reported between 2003 and 2013. The ramifications of these accidents are often severe, frequently resulting in high casualties and considerable environmental damage. The number of fatalities associated with these maritime accidents has shown fluctuations over the years, with a notable peak of 325 victims in 2018. More recently, in 2022, there were 69 reported fatalities, highlighting an ongoing risk to human life. An in-depth analysis of the causes of these accidents reveals that human error is the primary factor, responsible for 65% of the incidents recorded from 2005 to 2010.

This includes mistakes made by crew members, misjudgments, and failures in following safety protocols. Following human error, technical issues constitute another significant cause, encompassing machinery failures, structural defects, and other technical malfunctions that compromise the vessel's safety. Weather conditions also play a critical role in the occurrence of ship accidents, with adverse weather such as storms, heavy rains, and rough seas contributing to the perilous conditions that lead to maritime disasters. These findings underscore the multifaceted nature of ship safety challenges in Indonesia, highlighting the need for comprehensive measures addressing human factors, technical reliability, and environmental conditions to mitigate the risk of future accidents. Despite efforts to improve maritime safety, enforcement of regulations remains a challenge, and the Indonesian government faces difficulties in ensuring compliance with international standards and national regulations. Studies emphasize the need for enhanced safety measures, improved crew competency, and better operational practices to mitigate risks associated with ship accidents.

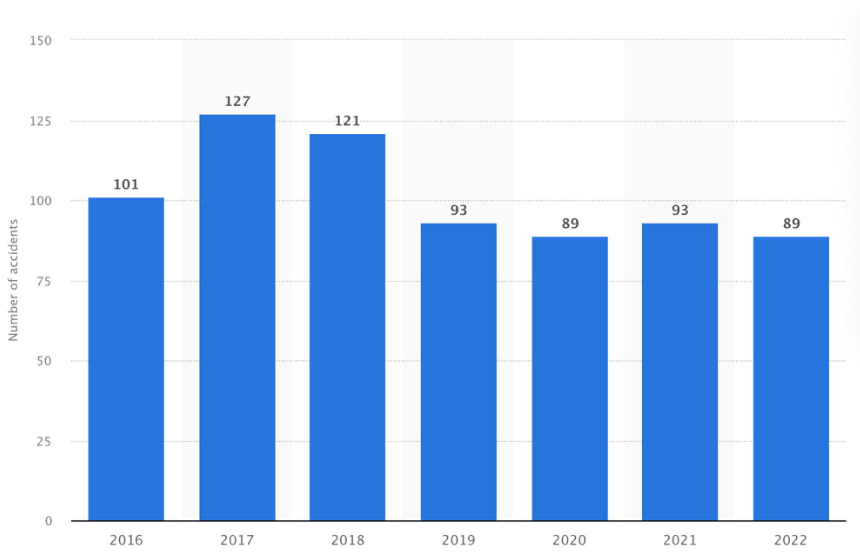

Figure 2. 3 Number of ship accidents in Indonesia from 2016 to 2022

(Source : Statista.com)

2.5 Failure Mode and Effects Analysis (FMEA)

As the application of risk assessment methodologies develops in various areas, academic research now employs a variety of qualitative and quantitative risk assessment methods (Ceylan et al., 2021). FMEA is one of these methods, with high risk detection, categorization, analysis, and computation capabilities, as well as systematic simplicity (Bhattacharjee et al., 2020). FMEA is a highly structured approach through which all potential failure modes of a system and their effects can be identified, evaluated, and prioritized. The technique can result in cost/time-savings when employed during early design stages by exposing probable operational challenges and eliminating cascading failures. In this technique, the risk score for each failure mode is obtained by .The major goal of FMEA is to enable researchers to discover potential defects in a system as well as to examine the probability, repercussions, and non-detectability of different failure modes in order to choose which failures should be addressed first. Considering the FMEA method, the RPN value is obtained by multiplying the Severity (S), Non-Detection (D), and Occurrence (O) scores as shown in Equation (1).

$$RPN = O \times S \times D$$

The risk variables S, O, and D are ranked for each failure mode on a scale from 1 to 10. As a result, the range of RPN values for various failure situations is 1 to 1000. In order to characterize failure scenarios, engineers ought to designate a threshold RPN value. For example, any failure modes whose RPN values over 100 are subject to precautions under the present FMEA technique. Corrective action is therefore deemed necessary for a failure mode with an RPN of 100, whereas a failure mode with an RPN of 98 is classified as "consider corrective action." There has been a lot of criticism directed at the fundamental approach that governs the priority of failure modes and the multiplication of risk variables to obtain RPN.

2.6 Failure Mode and Effect Criticality Analysis (FMECA)

FMECA is an extension of the Failure Mode and Effects Analysis (FMEA) method, which examines manufacturing tools or processes, types of failures, and their consequences. FMECA includes a criticality analysis that ranks the identified failure modes according to their risk priority number (RPN), which is generated by multiplying the severity, occurrence, and detection variables. FMECA is used in a variety of industries including manufacturing, construction, and aerospace, to detect and reduce potential hazards. It helps businesses improve their products and processes, eliminate defects, and increase overall efficiency (Nugraha Adz Zikri & Suwarningsih, 2023)

2.6.1 Function, Functional Failure, Failure Mode and Effect Setup

The first stage in implementing the FMECA model is to specify the role of each cooling system component. The function that has been determined is then used to identify the possibility of functional failure. The next step is to determine the failure mode or cause of failure that results in functional failure. The impacts of failure are determined by the impact made by each failure mode (Siswantoro et al., 2020).

2.6.2 Determination of Criticality Model

Based on ABS Classification recommendations, the criticality model is utilized to quantify the risk level in each failure mode and consequence. This critical model takes into account the operational, safety, and containment loss likelihood and severity variables. Tables 2.1-2.2 indicate the criteria for severity and likelihood levels in Figure 2.6 and the danger level is depicted as a 4x5 matrix. The main engine supporting system's critical level is ly evaluated using Failure Mode and Effect Criticality Analysis (FMECA)

2.7 Step of Failure Mode and Effect Criticality Analysis (FMECA)

According to the American Bureau of Shipping, (2020), Failure Mode and Effect Criticality Analysis is a development of FMEA which is equipped with an assessment of the criticality of a problem. This assessment is carried out openly and clearly, thus helping to identify the most critical problems and determine the right corrective steps.

2.7.1 Identification of Operating Modes and Operating Contex

There are four distinct operation modes.

a. Operating Mode at Full Speed (When Sailing at Sea): This mode involves the ship operating at its maximum cruising speed while navigating open waters. During this mode, the propulsion system is running at high capacity to achieve and maintain optimal speed, often determined by the vessel's design and operational requirements. Systems such as the engine, fuel management, and navigation equipment are all set to handle the demands of high-speed travel.
b. Operation Mode in Congested Areas (When Sailing in Areas with Heavy Ship Traffic): In this mode, the ship navigates through areas with dense maritime traffic, such as busy ports, shipping lanes, or coastal regions with significant vessel activity. The focus is on precise navigation, collision avoidance, and adherence to maritime traffic regulations.
c. Maneuvering Operating Mode (When Performing Maneuvers on the Side): This mode involves executing precise movements such as docking, undocking, or changing course in tight or confined spaces. Maneuvering requires fine control of the ship's propulsion and steering systems, including thrusters and rudders, to achieve accurate positioning and movement.
d. Loading and Unloading Operation Mode (When Carrying Out the Cargo Handling Process): During this mode, the ship is engaged in cargo operations, which include loading or unloading goods at port facilities. This involves coordinating with port staff, operating cargo handling equipment (such as cranes, winches, and conveyors), and ensuring the safe and efficient transfer of cargo.

Multiple factors must be taken into account when establishing the operating context.

a. Serial Redundancy involves the use of duplicate standby systems or equipment designed to ensure uninterrupted operation of functional groups. In this setup, the primary system handles the operational load while a secondary, standby system remains idle but ready to take over in case of a failure. The operational environments for active and standby systems can differ, leading to different failure modes: active systems exhibit visible failures, whereas standby systems might experience concealed issues. This approach ensures that if the active system fails, the backup system can seamlessly engage, minimizing downtime and maintaining overall system reliability.
b. Parallel Redundancy features systems or equipment that operate simultaneously, each capable of handling the full demand independently. This means that if one system fails, the remaining system(s) can continue to operate, though potentially at an increased load or reduced capacity. In some configurations, a system designed for parallel operation can also serve as a backup, providing an additional layer of redundancy. This method enhances system reliability by distributing the operational load and providing immediate failover capabilities in the event of a malfunction.
c. Performance and Quality Standards require that systems or equipment operate at predetermined levels of performance or deliver services that meet specific quality criteria. These standards ensure that equipment functions efficiently and reliably within the expected parameters, and any deviations from these standards can impact the overall performance and reliability of the system. Adherence to these standards is crucial for maintaining operational effectiveness and meeting customer or regulatory expectations.
d. Environmental Standards mandate compliance with international, national, and local regulations concerning environmental protection. These standards cover aspects such as emissions, waste management, and energy consumption, ensuring that systems and

operations do not adversely impact the environment. Adhering to these regulations is not only a legal requirement but also supports sustainable practices and minimizes environmental harm.

e. Safety Standards address operational hazards and outline preventive measures to protect the workforce. These standards include protocols for safe operation, emergency procedures, and personal protective equipment (PPE). Ensuring compliance with safety standards is essential to prevent accidents and injuries, safeguarding both personnel and equipment.

f. Operational Continuity for Ship Propulsion Systems requires that the propulsion system runs continuously, except during docking periods. The ship's service electrical power must also operate without interruption. Therefore, meticulous planning of system setup and maintenance procedures is necessary to guarantee reliability and avoid disruptions.

Operating Context of Diesel Engine

The propulsion system consists of a *Manufacturer* Diesel Type *Model Number* low-speed diesel engine rated 16,860 kW Maximum Continuous Rating (MCR) at 91 RPM, coupled directly to a shaft supported by one intermediate bearing and two stern tube bearings, and driving a fixed pitched propeller.

Common Characteristics	*Operating Modes*			
	At Sea	*In Congested Waters*	*Maneuvering Alongside*	*Cargo Handling*
Environmental Parameters	Nominal ambient air temperature: 25°C. Range from –29°C to 45°C Barometric air press (dry) 101.3 kPa Absolute Nominal seawater inlet temperature: 32°C, 2.0-2.5 bar. Range from –2°C to 50°C Cooling FW nominal temperature: 25°C, 2.0-2.5 bar. Max. temp. 90°C L.O. max. supply temp. 60°C, 4.3 bar with exception of Camshaft L.O. max. supply temp. 50°C, 4 bar F.O. supply max. temp. 150°C at 4 bar.	Dependent on geographical location If ports to visit are known, list environmental parameter ranges.	Dependent on geographical location If ports to visit are known, list environmental parameter ranges	Not used
Manner of Use	Propels vessel at 20 knots at 85% of MCR. Capable of continuous operation for up to 22 days. Single-engine installation	Propels vessel from 2 to 10 knots, with reversing and stopping capabilities	Propels vessel from 2 to 10 knots, with reversing and stopping capabilities, and assists in mooring	Not used
Performance Capability	To output 16,860 kW @ 91 RPM; controllable from bridge, centralized control station and locally	To output at 30 to 85 RPM; reversing at 63 RPM, controllable from bridge, centralized control station and locally	To output at 30 to 85 RPM; reversing at 63 RPM, controllable from bridge, centralized control station and locally	Not Applicable

Figure 2. 4 Example of Operation Context

2.7.2 Define Vessel Systems

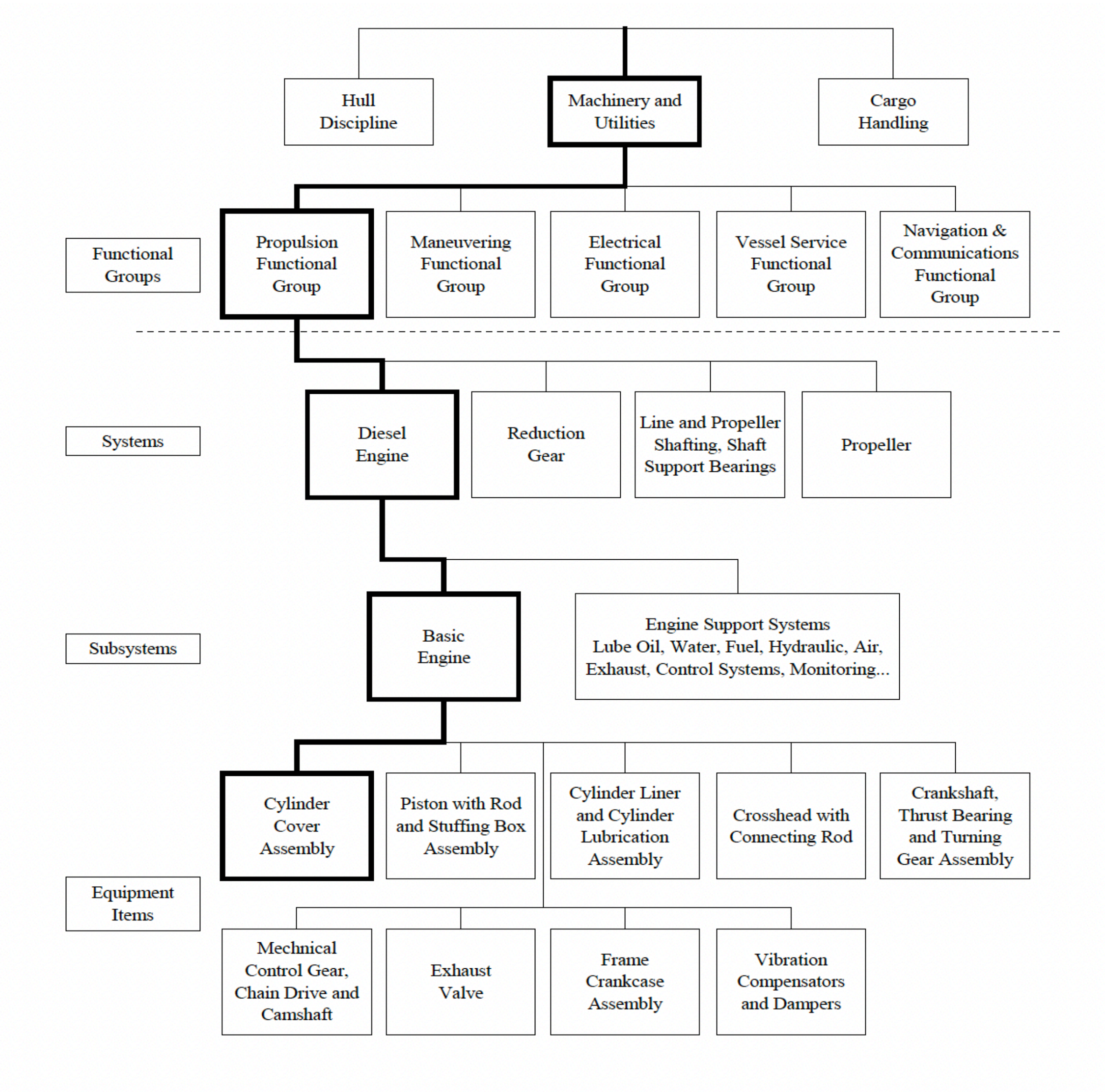

Figure 2. 5 Ship's System Level Division

Starting with the hull, machinery and utilities, and cargo handling, ships are arranged into disciplines and functional groups. Subsystems and equipment items are the next two layers of agreement for system partitioning. Boundaries are set for every discipline and subset of detail through this division. Furthermore, these divisions serve as the fundamental structure for delineating the ship's operational attributes.

2.7.3 Development of Block Diagrams

Functional block diagrams are a useful tool for visualizing interfaces and interdependencies between the many components that make up a system; they are used to show how various sections of the system interact with one another. By highlighting the system/subsystem chains that are necessary for successful operation and making it easier to identify potential failure modes and effects, causes of failure, and potentially hidden failure locations, a block diagram serves the primary purpose of providing a high-level basic understanding. Dependency diagrams, also known as reliability block diagrams, are a specific kind of block diagram that are very helpful in describing the physical boundaries and scope of a failure mode and effects analysis (FMEA). This is particularly true when the FMEA entails demonstrating redundancy.

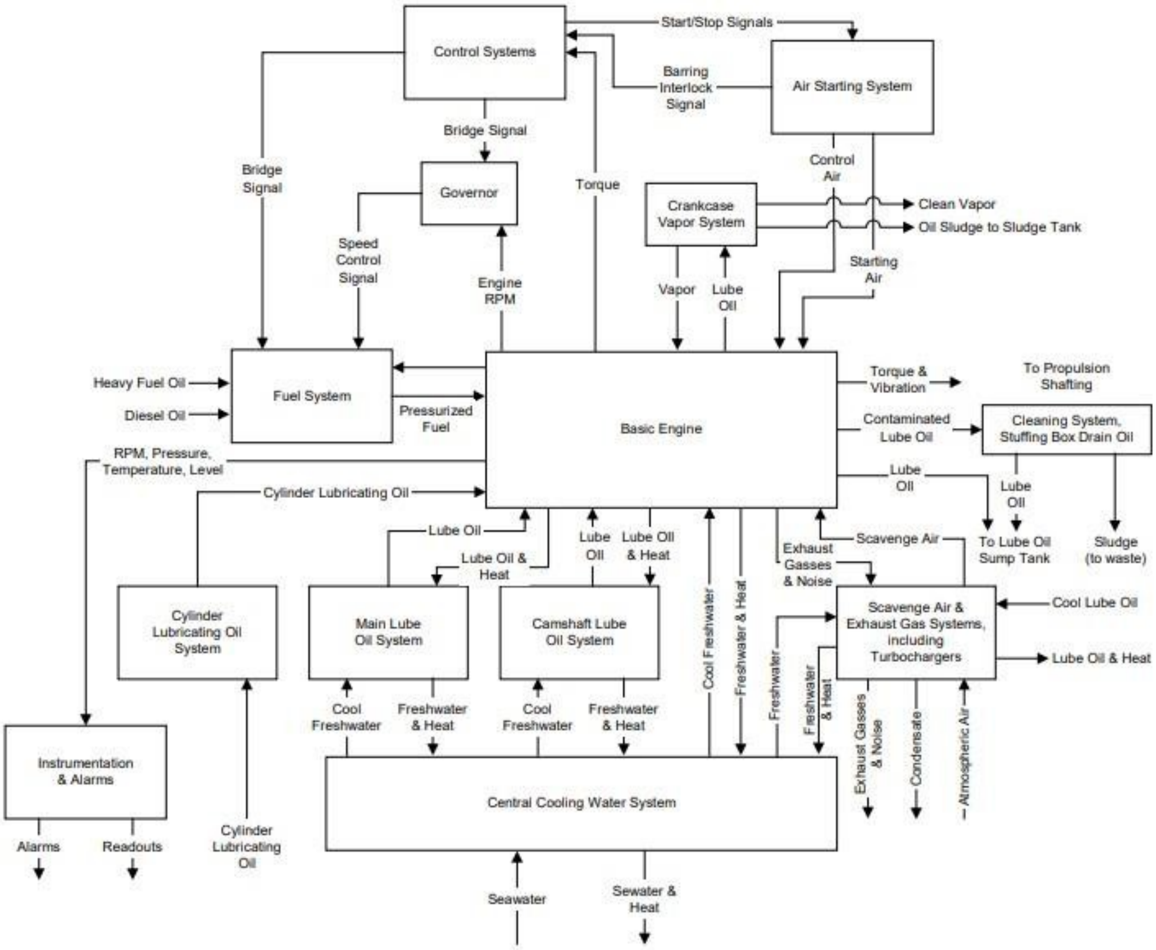

Figure 2. 6 Example of Ship Block Diagram

2.7.4 Identification of Functional Failure and Failure Effect

the focus on failure types pertains specifically to the failure of individual components within a system. The analysis involves understanding how each component functions and how its failure impacts the overall system. When implementing Failure Modes, Effects, and Criticality Analysis (FMECA), every potential functional failure of components is meticulously examined by evaluating the consequences of such failures at the next higher level of the system hierarchy. This approach aims to assess how component failures affect the overall performance and reliability of the system. To effectively conduct this analysis, it is crucial that both components and systems are thoroughly specified, including their operational roles and interactions. This detailed specification ensures that the FMECA process accurately identifies and prioritizes failure modes based on their impact on system performance, enabling more effective risk management and mitigation strategies.

Function			*Functional Failure*	
Item No.	*Function Statement*	*Function Type*	*Item No.*	*Functional Failure Statement*
1	Transmit 16,860 kW of power at 91 rpm to the propulsion shafting	Primary	1.1	No transmission of power to the propulsion shafting
			1.2	Transmits less than 16,860 kW of power to the propulsion shafting
			1.3	Transmits more than 16,860 kW of power to the propulsion shafting
			1.4	Operates at less than 91 rpm (Reduce rpm)
			1.5	Operates at more than 91 rpm
2	Exhaust engine gases after the turbochargers are to be in the range 275 to 325°C	Secondary	2.1	Exhaust gases are less than 275°C
			2.2	Exhaust gases are more than 325°C
3	Provide engine overspeed protection at 109 rpm	Secondary	3.1	No activation of overspeed protection
			3.2	Overspeed protection activates at less than 109 rpm
			3.3	Overspeed protection activates at more than 109 rpm
			3.4	Overspeed protection activates and cannot be reset

Figure 2. 7 Examples of Funtion And Functional Failure

2.7.5 Determine the Failure Mode

Failure type in this study pertains to the system failure of a component. The text explains how the system operates and the functional relationships between component failures. When implementing FMECA, all functional failures of components will be investigated by assessing the consequences of the failure at the subsequent higher level. This is intended to assess the effect on the overall system performance, therefore, components and systems need to be fully specified.

a. Bottom-Up

According to ABS, The bottom-up approach is used to assess whether equipment failure modes can result in local effects that contribute to functional failures, which in turn lead to the occurrence of the desired end effect. The bottom-up approach helps ensure that each item of equipment is thoroughly analyzed and that all plausible equipment failure modes are considered.

The following are the steps of Bottom-Up FMECA:

1) Select the equipment item to analyze
2) Identify potential failure modes for that equipment item
3) Select failure modes for evaluation
4) Determine the failure characteristics (e.g., wear-in, random, wear-out) for the failure modes
5) Determine the local, next higher level, and final effects for the postulated failure mode
6) If the final effect results in a consequence of interest, determine the cause of the failure mode
7) Determine the criticality of the failure mode using a risk decision tool

No.: 15	Description: Camshaft Lube Oil Pump					
Item	**Failure Mode**	**Causes**	**Failure Characteristic**	**Local Effects**	**Functional Failures**	**End Effects**
15.1	Fails off while running (on-line pump) (evident)	Pump motor failure Pump seizure Pump motor control failure Pump coupling failure	Random failure, Wear-out failure Random failure, Wear-out failure Random failure, Wear-out failure Wear-out failure	Interruption of lubrication to the camshaft, requiring the standby pump to be started	No flow of lubricant to the camshaft	Brief shutdown of the engine until standby lube oil pump is started
15.2	Starts prematurely/ operates too long (standby pump)					No effect of interest
15.3	Operates at degraded head/flow performance (on-line pump) (evident)	Worn pump gears	Wear-out failure	Insufficient pressure or flow of lubricant to the camshaft, resulting in a low pressure alarm and requiring standby pump to be started	Flows less than 10.3 m^3/hr of lubricant to the camshaft Flows lubricant to the camshaft at a pressure less than 4 bar	Brief engine shut down until the standby pump is operating

Figure 2. 8 Example of Bottom-Up FMECA Worksheet

b. Top-Down Approach

The top-down approach in maintenance analysis begins by thoroughly examining each function and functional aspect of a system to understand how failures impact overall system operation. This method starts with a high-level overview, focusing on the system's intended functions and how their failure could disrupt operations. By assessing the consequences of functional failures, the approach aims to pinpoint how these failures affect system performance and identify the critical equipment and components involved. The analysis extends to evaluating whether the observed functional failures align with the anticipated end effects or performance outcomes, providing a clear picture of the system’s operational integrity.

Subsequently, the top-down approach delves into identifying specific equipment failure modes that could lead to the functional failures previously identified. This involves a detailed breakdown of potential fault conditions and their effects on the system’s performance. The approach maps out which pieces of equipment are most likely to cause the functional failures and evaluates the mechanisms through which these failures manifest.

The following are the steps of Top-Down FMECA:
1) Determine the function for analysis
2) Determine the functional failure for evaluation
3) Determine local effects and final effects for the functional failures performed
4) If the end effect results in an interesting consequence, determine the equipment failure that could result in the functional failure
5) Determine failure characteristics (e.g. wear-in, random, wear-out) for failure modes
6) Determine the criticality of the failure mode using a risk decision tool 6)
7) Repeat the steps until all functions and functional failures are evaluated

No.: 25	Description: Transmit 16,860 kW at 91 RPM to the propulsion shafting				
Item	**Functional Failure**	**Failure Causes**	**Failure Characteristic**	**Local Effects**	**End Effects**
25.1a	No transmission of torque to the propulsion shafting	External rupture of the cylinder cover (evident)	Wear-in, Random, Wear-out	High engine vibration, requiring a shutdown Rupture of fuel oil line, releasing fuel oil into the engine room Catastrophic release of cylinder pressure, causing shrapnel to be released in the engine room Partial loss of containment of cooling water	Potential injury to personnel if hit by shrapnel Damage to cylinder cover and/or piston Vessel out of service for a time to make repairs
25.1b		Loosened piston rod studs at the crosshead (evident)	Wear-out	Relative motion between two parts, fretting Studs eventually break if left undetected	Engine damage due to a loose piston rod Vessel out of service for a time to make repairs
25.1c		Restricted oil passageway in the piston rod (hidden)	Wear-out	Overheating of piston crown, potentially causing piston failure	Damage to the piston Vessel out of service for a time to make repairs

Figure 2. 9 Example of Top-Down FMECA Worksheet

2.7.6 Determine the Severity Level

This stage determines the outcomes of the failure mode. The ABS Guidance Note on Reliability-Centered Maintenance categorizes failure impacts into four kinds.

Table 2. 1 Severity level based on loss of containment (C), safety (S) and operational (O)

Level	Impact Category	Operations
		Ship Fleet (core operational)
1	Very Light	Ship Fleet disruption (outside of docking time) ≤ 1 Day (annually)
2	Mild	Ship Fleet disruption (outside docking time) > 1 Day to ≤ 3 Days (annually)
3	Medium	Ship Fleet disruption (outside of docking time) > 3 Days to ≤ 8 Days (annually)
4	High	Ship Fleet disruption (outside of docking time) > 8 Days s.d. ≤ 14 Days (annually)
5	Very High	Ship Fleet disruption (outside of docking time) > 14 Days (annually)

2.7.7 Determine the Current Likelihood

During this step, a frequency analysis is conducted for each specific failure. Below are the frequency categories:

Table 2. 2 Likelihood level

Probability Rating	Probability	Frequency	Probability of Likelihood
1	Very Rare	Does not occur or 1 time a year	<10% probability of occurrence per period
2	Rarely Occurs	May occur 2 times a year	Probability of 10% to. 25% occur per period
3	Moderate (Occurs Occasionally)	May occur 3 to 4 times a year	Probability >25% to. 40% occur per period
4	Happens Often	May occur 5 to 6 times a year	Probability >40% to. 55% occur per period
5	Almost Certain to Occur	May occur more than 6 times a year	Probability of >55% occurring per period

2.7.8 Analyze the Current Risk

A risk matrix is created at this point, which is a table that outlines the risk level by considering both the repercussions and the frequency of failure. The criteria for creating this risk matrix are derived from the ABS Guidance Notes on Reliability-Centered Maintenance.

Table 2. 3 Table risk matrix

Risk Group	Risk Level Score
Low	(1-5)
Low-Medium	(6-11)
Medium	(12-15)
Medium-High	(16-19)
High	(20-25)

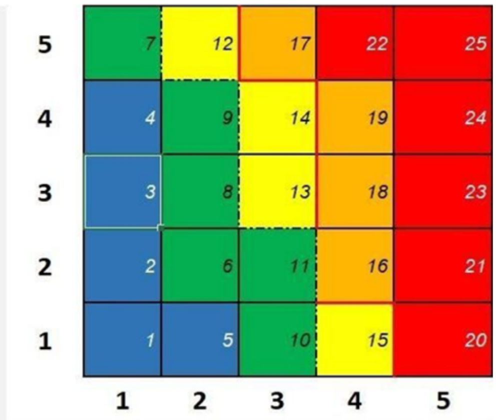

Figure 2. 10 Risk Matrix

2.8 Maintenance Task Selection Analysis

The analysis in this stage makes use of the job selection flow diagram found in the ABS guidance on reliability-centered maintenance. In order to identify the best management plan to solve current failures and try to prevent future ones, the task selection flow chart is utilized as the analysis rationale.

2.8.1 First Selection Decision

This stage entails assessing whether the risk linked to the failure mode is the most or least significant risk, and giving a level of certainty to the determination.

a. Highest Risk
The highest risk failures are typically unmanageable with routine maintenance. Often, significant modifications to the design or operation of the equipment are needed to bring the risk down to a manageable level. The FMECA analysis should be updated and each pertinent failure should be reevaluated utilizing the RCM Task Selection Flowchart upon the discovery of significant changes.
b. Lowest Risk
Failures with the lowest risk are assigned a low priority and are often considered acceptable without the need for specific failure management strategies. These low-risk failures typically have minimal impact on overall system performance, safety, and operational efficiency, making them less critical to address immediately. As a result, resources can be focused on higher-risk areas where the consequences of failure are more severe. However, while these low-risk failures may not require immediate or specialized management, they are still monitored to ensure that their impact remains negligible and does not escalate over time. This approach allows for a balanced allocation of maintenance efforts, ensuring that critical issues receive the attention they need while maintaining overall system reliability and functionality.
c. Confidence in The Risk Characterization
The degree of confidence in characterizing the risk and its potential use in the RCM flow chart without additional thought is reflected in the confidence level. Low confidence suggests that more information is required before the risk can be employed in the decision-making process, whereas high confidence shows that the risk definition can be relied upon with a sufficient degree of confidence. Failure modes are assessed using the RCM Task Selection Flow Diagram and are thought to have a moderate risk profile.

2.8.2 Second Selection Decision

Condition monitoring jobs are preferred for being the most technically sound and cost-effective solution. The team needs to assess if failures may be controlled through condition monitoring tasks by choosing certain tasks and establishing suitable intervals for doing them. Here are the criteria to consider when making this decision:

a. Maintenance Task Selection Criteria

Tasks related to condition monitoring should be feasible and efficient, considering factors such as ease of implementation, failure detection success rate, and cost-effectiveness in comparison to the repercussions of failure. By taking into account the anticipated risk reduction and contrasting it with the allowed level of risk, we should assess the possible risk reduction brought about by the execution of condition monitoring duties.

b. Determination of Maintenance Task Intervals

Real failure data should ideally be used to determine proactive maintenance task intervals, however this is typically not feasible. As a result, general P-F interval data, manufacturer guidelines, existing job intervals, and team experience can all be used to estimate maintenance task intervals. The task interval for condition monitoring tasks should give enough warning of failures to allow for prompt preventive action. It is recommended to arrange maintenance task intervals to be less than half of the expected P-F interval.

2.8.3 Fourh Selection Decision

Identify if the failure mode may be categorized as overt or covert failure.

1. Evident Failures

Clear Failures are those that are immediately noticeable to the operational crew during normal operating conditions. These failures are characterized by their obvious impact on the system's functionality, making them readily apparent without requiring further intervention. For instance, if a critical function or component fails, its absence or malfunction will be visibly evident during routine operations. This could include, for example, a major piece of equipment that stops working entirely, causing a noticeable disruption in the system's output or performance. Such failures are often associated with visible symptoms like error messages, alarms, or physical malfunctions that are easily detectable by the crew. Clear failures typically do not require sophisticated diagnostic tools or extensive analysis to identify; their presence is obvious and demands immediate attention to restore normal functionality and prevent operational disruptions.

2. Hidden Failures

Hidden failures are failures that will not be detected by the operations crew when they occur. Generally, hidden failures will only come to light after the failure or incident has occurred. For example, the failure of an unsecured protective device from failure is a common type of hidden failure. Although there is no direct impact of these hidden failures, the consequences can increase the risk of multiple failures. If the failure is hidden and there is no condition monitoring, scheduled maintenance planning or combination of tasks that will ensure an acceptable level of risk, the team must decide which failure identification tasks are required to manage the failure.

2.8.3 One-Time Changes

In order to assess the efficacy of a single modification, the team needs to identify possible alterations and take into account:

a. Tolerable risk level.
b. Minimization of risk to an acceptable level without additional decrease.
c. Cost efficiency.

d. Potential maintenance duties.

2.8.4 Rounds and Routine Servicing

In addition to the previously mentioned maintenance recommendations, it is essential to develop a comprehensive plan and routine for inspection tasks. These inspections play a pivotal role in preserving the stability and consistency of the failure rate curve for specific failure modes. By systematically scheduling and conducting regular inspections, potential issues can be identified and addressed before they escalate into significant failures. This proactive approach helps maintain the reliability of equipment and systems, ensuring that any deviations from expected performance are promptly corrected. Effective inspection routines not only help in tracking the performance and wear of components but also contribute to refining maintenance strategies by providing valuable data on failure patterns and root causes, thereby optimizing overall asset management and extending the lifespan of critical equipment.

2.8.5 Maintenance Task Allocation and Planning

Maintenance chores resulting from RCM analysis should be categorized as follows:

1. Task Category:

a) Category A: Tasks feasible for execution by the ship's crew while at sea.
b) Category B tasks need collaboration between equipment vendors or the use of dockside facilities.
c) Category C: Tasks to be completed at a dry dock facility.

2. Task Interval Adjustment:

Task intervals identified through RCM analysis may not correspond with existing time-based maintenance schedules. Thus, it is essential to incorporate these job intervals into the regular maintenance schedule.

No.: 3		Description: **Cylinder liner, including cylinder lubrication passageways and cooling jacket**											
Item	Failure Mode	Failure Char.	H/E	Effects			Risk Characterization (1)			Task Selection (2)			
				Local	Functional failure	End	S	CL	CR	Proposed Action(s)	PL	PR	Disposition
3.4	Worn cylinder liner	Wear-in Random Wear-out	H	Loss of compression in the affected cylinder, causing reduced engine performance Excessive consumption of lube oil during combustion	1.2, 13.1	Propul-sion is reduced result-ing in vessel delays	Propul sion SL- 2	Occa-sional	Medium	Visual inspection of the cylinder liner with a borescope via the scavenge port – 2000 hr	Remote	Medium	
										Recondition the cylinder liner – 8000 hr	Remote	Low	
3.5	Restrict ed cylinder oil passage -ways	Random Wear-out	H	Uneven cylinder liner wear or "clover leafing"	1.2, 13.1	Propul-sion is reduced result-ing in long vessel delays	Propul sion SL- 3	Occa-sional	High	Preventative Maintenance plan for lube oil service system	Remote	Medium	Develop detailed instructions for this task

Figure 2. 11 Example of Maintenance Task Selection Worksheet

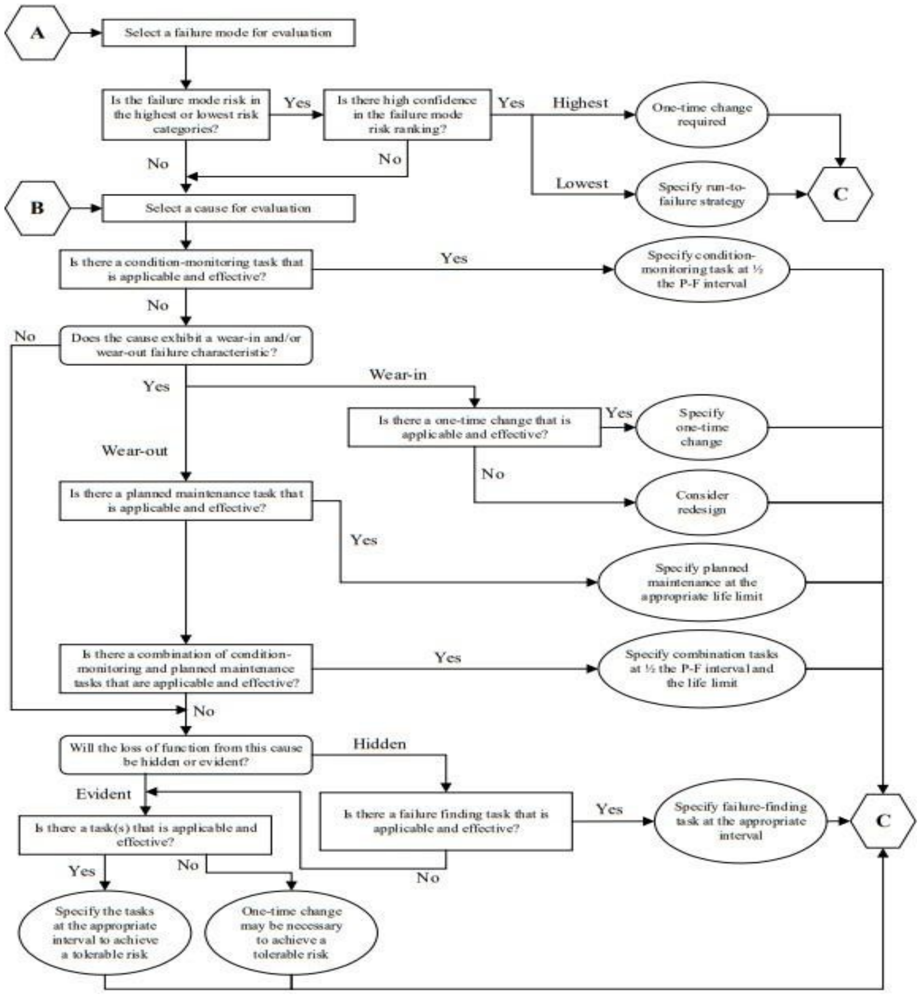

Figure 2. 12 Logic Tree Analysis

Maintenance Category(1):	**Category A**
Functional Group:	**Propulsion**
System:	**Diesel Engine**
Equipment Item:	**Basic Engine**
Component:	**Cylinder liner, including cylinder lubrication passageways and cooling jacket**

Task	*Task Type(2)*	*Item No.*	*Risk*		*Frequency*	*Procedure No. or Class Reference*	*Comments*
			Current	*Projected*			
Turn engine at least one revolution prior to starting, check if indicator valves on cylinders leaks fluid	AAET	3.1	High	Medium	Perform before engine startup	*List the Task Procedure No. or Operating Instruction No. here*	
Visual inspection of the cylinder liner with a borescope via the scavenge port	CM	3.3, 3.4,	High	Medium	2000 hr		Inspection is to detect corrosion, erosion, cracking and plugging
Preventative Maintenance plan for lube oil service system	PM	3.5	High	Medium	8000 hrs		Develop detailed procedures for this task
Clean the scavenge air ports	PM	3.6	Medium	Low	4000 hr		May be required sooner based on results of inspection of cylinder liner
Cooling water analysis	CM	3.7, 3.8	Medium	Medium	1000 hr		Use results for water treatment as necessary
Clean the freshwater cooling system	PM	3.7, 3.8	Medium	Medium	8000 hr		
Recondition the cylinder liner	PM	3.4	Medium	Low	8000 hr		To restore honing pattern to cylinder walls and therefore ability to hold lube oil

Figure 2. 14 Example of Summary Category

2.9 Maintenance

Maintenance reflects a significant evolution in asset management and care over time. Initially, maintenance was reactive, addressing issues only after they occurred. With the advent of the industrial revolution, preventive maintenance was introduced, focusing on routine care to prevent breakdowns. By the mid-20th century, time-based maintenance became common, although it often proved inefficient. The late 20th century saw the rise of condition-based and predictive maintenance, utilizing real-time data and technology to schedule maintenance more effectively. Entering the 21st century, advanced technologies such as IoT and big data analytics have further transformed maintenance practices, leading to more proactive, data-driven approaches that enhance reliability, efficiency, and safety in asset management.

2.9.1 Maintennace History

1. The First Generation

The time frame prior to World War II is covered by the first generation. Because industries at the period did not rely much on machinery, they did not give downtime much thought. Most managers did not place a high premium on preventing equipment breakdowns. The majority of equipment was built simply and with surplus capacity at the same time. It was dependable and simple to fix as a result. Because of this, regular maintenance is limited to simple tasks like basic cleaning, servicing, and lubricating. Additionally, fewer talents were needed than they are now (Moubray, 1997).

3. The Second Generation

The emphasis on downtime tightened as the dependence on machines grew. Preventive maintenance was born out of the realization that equipment breakdown could happen unexpectedly and needed to be avoided. During the 1960s, this primarily entailed routine equipment maintenance. When compared to other operating expenditures, maintenance costs also started to rise dramatically. As a result, maintenance planning and control systems, which aid in managing maintenance, grew in popularity and are now a crucial component of maintenance procedures. In the end, people began searching for strategies to extend asset life due to the rise in fixed asset investments and the notable rise in capital expenses (Moubray, 1997).

4. The Third Generation

The mid-1970s marked significant changes in the industry, categorized into new expectations, research, and techniques (Moubray, 1997). Downtime affected productivity, especially in sectors like mining, manufacturing, and transportation, where just-in-time systems exacerbated the impact of minor breakdowns. Rising safety and environmental standards forced organizations to adapt or face shutdowns. New research revealed that asset age and failure likelihood are less correlated than previously thought, uncovering six distinct failure patterns instead of just one or two. Rapid growth in maintenance concepts, including predictive maintenance and condition monitoring, shifted the focus from traditional overhauls to enhancing asset reliability and performance, driving the industry towards more efficient, reliable, and safe operations.

2.9.2 Type of Maintenance

Maintenance is categorized into planned and unplanned types, with emergency maintenance being necessary for urgent situations where immediate action is crucial to address serious incidents. Delays in performing maintenance during such critical times can result in severe repercussions, such as process interruptions, equipment damage, and safety hazards. As Corder (1996) explains, emergency maintenance is vital for managing these high-impact scenarios. Despite rapid technological advancements, many companies still struggle to improve their operational efficiency due to industrial competition and economic uncertainties. To boost productivity and asset availability, effective maintenance is crucial. This involves a range of technical and administrative tasks, including planning, supervising, monitoring, and controlling the maintenance of equipment, systems, or machines to restore and maintain their original functionality (Erbiyik, 2023).

Maintaining equipment in good condition is critical in the manufacturing process. Appropriate servicing and maintenance contribute to high availability and minimize production downtime. In contrast, power plants incur enormous financial costs for maintenance. As a result, it is critical to produce satisfactory production results while minimizing service expenses. Maintenance is described as all technical, administrative, and management operations taken during an item's life cycle with the goal of retaining or restoring it to a state where it can perform the required function (Molęda et al., 2023).

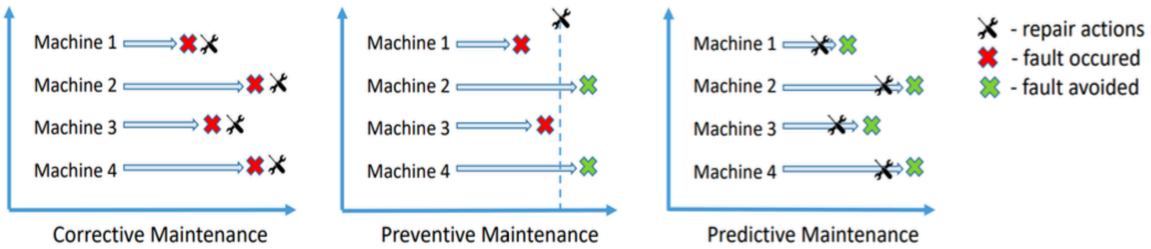

Figure 2. 13 Maintenance Type

(Source : learn.pm.com)

a. Corrective Maintenance

Corrective maintenance refers to taking action after a failure has occurred. This approach reduces the cost of servicing the equipment, extending the maintenance interval, but at the penalty of increasing the chance of equipment failure. A simple real-world example of corrective maintenance is changing a light bulb in a car. The item is only replaced when it burns out, and the drivers are prepared by keeping a set of bulbs on hand. As previously indicated, this strategy is best suited for non-critical, easily repairable equipment. A more proactive approach is needed for components whose failure could result in downtime, such as a steam boiler or turbine in a power plant (Molęda et al., 2023).

a. Preventive Maintenance

The goal of preventative maintenance is to avoid unplanned downtime by performing regular checks and replacements. Typical planned duties include lubrication, adjustments, oil changes, and sophisticated diagnostics. Maintenance intervals can be planned using manufacturer guidelines and quality factors such as MTBF and MTTF. Preventive maintenance keeps equipment in good condition and decreases the chance of downtime. However, it does not provide protection against unforeseen failures or problems in elements not covered by maintenance. The disadvantage also includes the need to plan maintenance and costs. Effective preventive maintenance planning in energy generating should connect maintenance intervals with plant availability requirements. (Molęda et al., 2023)

b. Predictive Maintenance

Predictive maintenance involves servicing when it is needed, typically just before a fault is expected. The essence of this approach is to anticipate a machine's health using repeated analysis or known features. Predictive maintenance is a type of condition-based maintenance in which we forecast future performance using present and previous indications. This strategy reduces both scheduled and unscheduled downtime. Planned downtime refers to preventive actions that can be better scheduled, whereas unplanned downtime refers to unanticipated breakdowns that can be avoided by regularly monitoring the equipment state (Molęda et al., 2023).

c. Proactive Maintenance

By using techniques including more precise maintenance methods, more planned maintenance scheduling, better component installation, and more efficient initial design, proactive maintenance seeks to increase maintenance effectiveness. To enhance the efficiency and performance of the planned maintenance program for every component, proactive maintenance in practice necessitates predictive and root cause failure analysis. This makes it possible to manage maintenance according to the life cycle of the component and how it affects the periodic performance assessment in between maintenance procedures.

2.10 Reliability Centered Maintenance (RCM)

Reliability-Centered Maintenance (RCM) is described as the process of determining what needs to be done to ensure that any physical asset continues to accomplish what its users expect it to do in its current operating context. The fundamental goal of RCM is to retain system functionalities rather than to keep the asset operational. The application of RCM necessitates a thorough understanding of the physical asset's operations as well as the nature of the failures that accompany those functions. Because of the specific treatment of each type of failure, it may neglect some occurrences that could effect, say, life expectancy or performance loss (Molęda et al., 2023).

Reliability-Centered Maintenance (RCM) is a logical engineering process aimed at defining maintenance tasks to ensure system reliability under specific conditions (Jardine, 2001). It emphasizes that the risks and consequences of failure are more critical than the equipment's technical characteristics. RCM focuses on proactive maintenance to avoid or reduce failures (Moubray, 1997) and involves preventive strategies based on effective planning and component replacement recommendations (Irawan, 1998). According to the American Bureau of Shipping (2016), RCM identifies the most effective maintenance approach to minimize failures and costs, with the goal of achieving reliability across all operational modes of a system (American Bureau of Shipping, 2004).

RCM focuses on finding answers to the following questions:

1. What are the functions and associated desired performance standards of the asset in its present operating context (functions)?

The asset owner must evaluate if each component fulfills the expected requirements by establishing the necessary work standards and ensuring that the asset functions according to the relevant specifications when employed. Thus, this stage marks the initial phase of the RCM process. Assets play a crucial role in the operations of a firm by contributing both physically and monetarily to its overall performance. Key functions include speed, output power, capacity, product quality, and customer pleasure. Each asset is supposed to provide standard functions such as safety for users and the environment, protection or efficiency while usage, structural integrity, and simplicity of control during operation.

a. Primary functions such as speed, output power, capacity, quality of each product and customers
b. The standard or expected functions of each asset or component include the following aspects: safety for users and the environment,
c. The function of assets, both from a physical and economic perspective, is very important in operations, because it allows asset owners to verify the contribution of each component to the overall performance of the company

2. In what ways can the asset fail to fulfill its functions (functional failures)?

Every part is designed with a specific purpose as outlined by the manufacturer's specifications. The asset owner anticipates the component to consistently meet these standards. Maintenance actions on components can only guarantee that the component will continue to function at a level below its original capacity or the capabilities it had when first manufactured. Functional failure happens when a component or system is unable to carry out the system function or complete tasks as per expected specifications.

3. What causes each functional failure (failure modes)?

Each component is created with a distinct function as specified by the manufacturer's guidelines. The asset owner expects the component to continuously adhere to these requirements. Maintenance actions on components can only ensure that the component will perform at a level lower than its initial capacity or the capabilities it had when first created. Functional failure happens when a component or system is incapable of performing the system function or completing tasks according to the expected requirements.

4. In what way does each failure matter (failure consequences)?

Consequences of concealed failures. This failure does not have a direct impact on the component, but if left unaddressed, it might lead to more severe damage. Operators may not immediately comprehend the consequences of this failure. Safety and environmental implications. This category encompasses potential dangers or life-threatening outcomes for both the operator and individuals closely associated with the component. Operational implications. This type of issue can have a direct impact on operations and production outcomes, leading to decreased product quality, lower output power, and increased repair costs throughout operations. Non-operational repercussions. This category encompasses repercussions that do not have a direct impact on production operations or operator safety. The impact involves repair expenditures directly caused by the breakdown.

5. What should be done to predict or prevent each failure (proactive tasks and task intervals)?

Scheduled based on condition, these precautions entail monitoring and assessing components while they are in use to detect signs of possible failure or malfunction. Preventive steps can be implemented to avoid more severe results. This category is subdivided into four primary subcategories: Condition monitoring approaches utilize specialized equipment for inspecting and maintaining components. Statistical process control involves monitoring fluctuations in product quality to avert issues. Primary effect monitoring procedures involve the use of inspection equipment for maintenance tasks. Inspection methods relying on forecasts and human expertise. Planned Recovery, this preventive measures in this category are performed irrespective of the components' state during maintenance. This maintenance is time-consuming because the components need to be deactivated or non-operational during the process. Scheduled disposal, this preventive approach entails replacing components based on their age, irrespective of any damage. This is done by considering the lifespan of the item and the higher probability of failure. If a component failure affects environmental safety, all items will be replaced.

a. Hidden failure consequences

   The impacts that arise from this type of failure do not directly affect the components, but if not properly identified, can cause more serious damage. Because the consequences of this failure are not directly visible to the component operator.

b. Safety and environmental consequences

   Consequences in this category occur when failure causes serious injury or even death to the operator or related parties who are in direct contact with the component.

c. Operational consequences

   Impacts of this type directly affect operations and production results due to factors such as reduced product quality, reduced output power, and the cost of repairs required during the operation process.

d. Non-Operational consequences

   Consequences in this category occur when the failure has no impact on production operations or operator safety. However, the impact that arises is the direct costs for repairs as a result of the failure.

6. What should be done if a suitable proactive task cannot be found (default actions)?

Scheduled identification of failures, this entails doing regular inspections on each component to ensure that they are functioning properly or have incurred any damage. Revise, These steps entail altering components and methods to restore a component to its original function. Run until the point of failure, this step entails doing operating tasks until the component becomes damaged. This occurs when the asset owner decides that the cost of maintenance to avoid damage is not justified by the potential losses.

a. Scheduled On-Condition

These preventive efforts include measuring and monitoring components during operation to identify conditions that indicate potential damage or malfunction (potential failure). This allows prevention before more severe impacts of damage or functional failure occur. In implementing scheduled on-condition, it is divided into four main categories, namely:

1) Condition monitoring techniqueswhich in this category requires special equipment to carry out inspections or maintenance actions on components.
2) Statistical process controlnamely a prevention technique carried out by applying diversity in the quality of the products produced
3) Primary effect monitoring techniqueswhich in this category uses monitoring inspection equipment in carrying out maintenance actions
4) Inspection techniques based on predictive and human sense.

b. Scheduled Restoration

Preventive actions in this category are carried out regardless of whether the component is damaged or not while the maintenance schedule is in progress. Therefore, in practice, this maintenance action requires a special time during which the component must be turned off or not operational.

c. Scheduled Discard

This preventive effort involves replacing components after they reach a certain age without checking whether the component is damaged or not. This action can be taken in the following situations:

1) The age of the item is obtained by identifying the possibility of increasing the rate at which failure occurs.
2) Most components have the ability to survive this lifespan and are carried out on all items if component failure has consequences for environmental safety.
3) What to do if a maintenance task cannot be found?

This action is chosen when appropriate and effective maintenance tasks are impossible to carry out, so it can be interpreted that this action is taken during a failed state. The default action includes the following things:

a. Scheduled failure finding

This action includes regular checks of each component to ensure that the component is still functioning properly or has been damaged.

b. Re-design

This action involves modifying components and procedures to restore the component's capabilities according to the desired function.

c. Run to failure

This action involves operating the component until failure occurs. This is done after the asset owner has identified and confirmed that maintenance actions to prevent damage do not provide comparable economic benefits. RCM focuses more on applying qualitative analysis to find components that may cause failure in a system. The seven questions above in the form of Failure Modes, Effects, and Critical Analysis (FMECA), as well as RCM task decisions, are included in the RCM worksheet.

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CHAPTER 3

RESEARCH METHODOLOGY

3.1 Research Flowchart

Figure 3.1 shows a flowchart that explains the method and flow of this research.

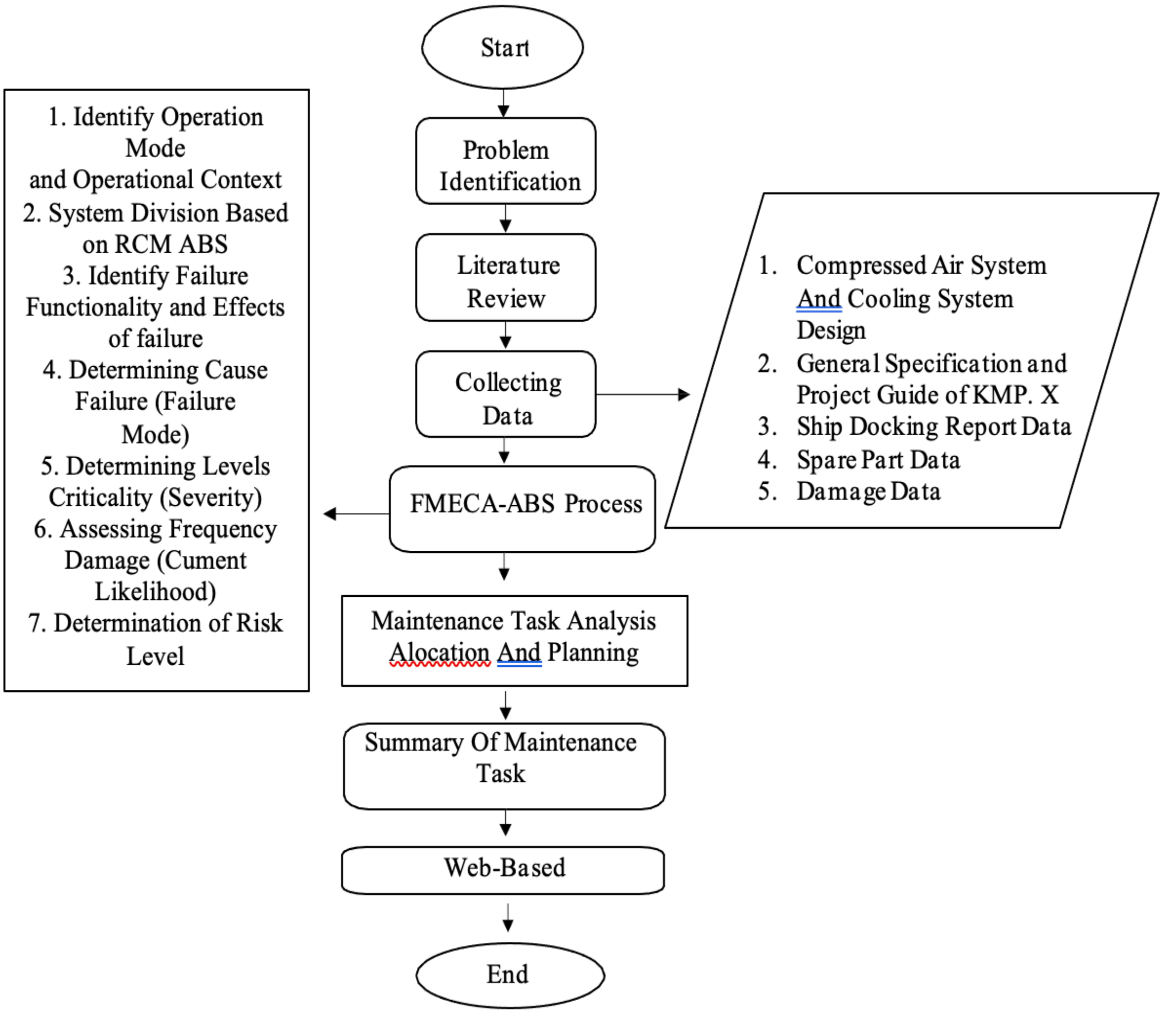

Figure 3. 1 Flow Chart

3.2 Identification of problems

The problem identified and stated then becomes the aim of this research, from here the research boundaries of problem assessment will also be determined. The outcomes of this final project may prove the failure modes and effects analysis (FMEA) on KMP. X compressed air system and cooling system.

3.3 Study of literature

In this Final Project, a comprehensive literature review is conducted, encompassing journals, prior research, and relevant books. The review focuses on topics related to the application of FMEA on KMP. X compressed air system and cooling system. The next step in carrying out this research is to conduct a literature study. This process is carried out by studying and understanding more in-depth information related to the topic being discussed and looking for related information that can be used as data and a basis for solving problems that have been previously formulated. In this process, a study is carried out on relevant literature that is trusted and can be accounted for in the form of scientific journals, books, guides or regulations from trusted organizations. The literature used and information taken are as follows:

3.4 Data collection

In principle, the data required for analysis using the RCM method in this research is qualitative in nature to support or answer questions in accordance with the RCM ABS Rules. In carrying out this research, the author will conduct a survey on the KMP. X ship owned by PT. X to collect data. Therefore, the data used for RCM analysis includes.

1. General Specification data from the KMP. X ship. This data is the basis for the research object and reference in carrying out FMECA analysis.
2. Cooling and compressed air design data which includes design drawings of the cooling and compressed air it self along with detailed drawings to determine the detailed condition of the cooling and compressed airsystem as well as the condition of the ship.
3. Damage/nonconformity and repair data are used to determine the history of damage and a list of repairs for cooling and compressed air that have a potential risk of failure and can be used to determine the appropriate type of maintenance for each component. This data was taken from the KMP. X damage report
4. Project guide of main engine and auxiliary engine.
5. Manual book data
6. Spare parts usage and component replacement data.
7. Ship docking report data.

3.5 Identify System Partition

Because ships consist of many complex systems and subsystems, it is helpful to divide them into functional groups and then into systems, subsystems, equipment items and, finally, components within each specific functional group.

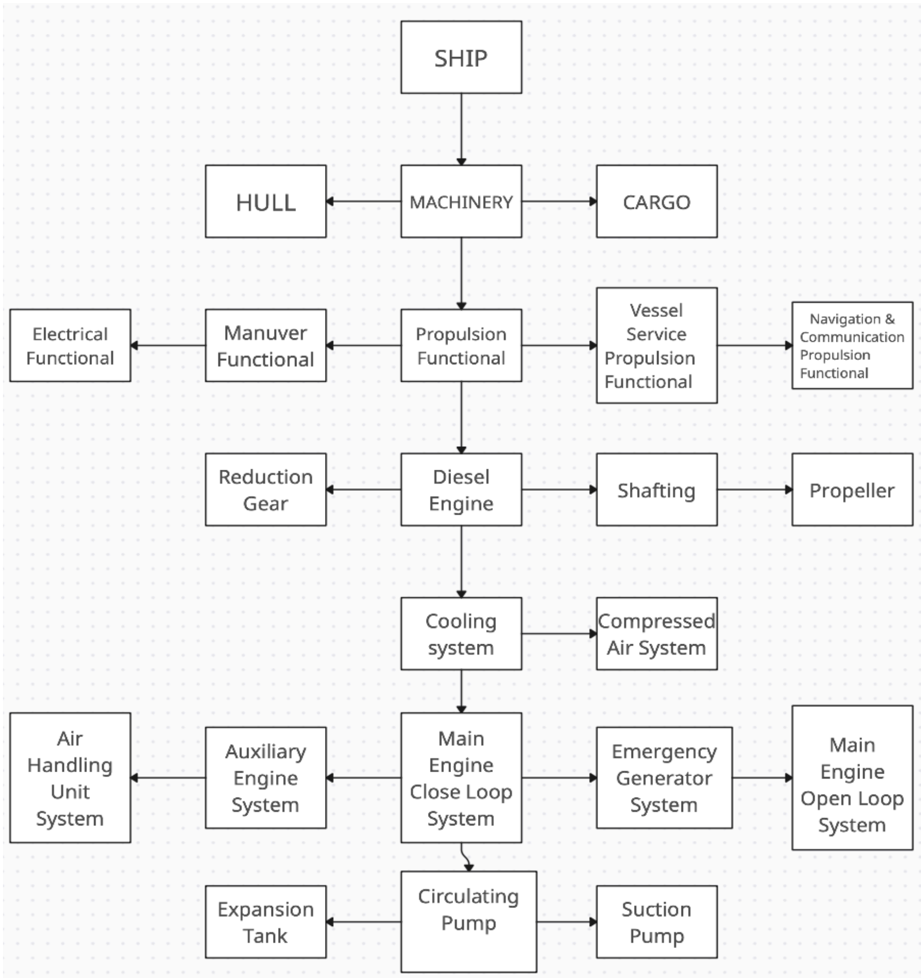

Figure 3. 2 System Partition

3.6 Failure Mode Effects and Criticality Analysis (FMECA)

Failure Mode, Effects, and Criticality Analysis (FMECA) could be a crucial component of the Reliability-Centered Maintenance (RCM) procedure. FMECA is commonly utilized as a reliability tool to pinpoint failure modes that negatively affect the system's overall reliability. The objective of this stage is to determine a cause-and-effect relationship among probable equipment failures, functional failures, and the consequences of functional failures. This relationship is essential for establishing maintenance and repair needs. Furthermore, it is important to assess the detectability and criticality of the discovered failure modes. Generally, there are two potential ways to FMECA. The bottom-up strategy begins at the lowest level determined during system partitioning, whereas the top-down approach starts at the top level. The author will utilize a bottom-up technique to perform Failure Mode Effects and Criticality

Analysis (FMECA) within the framework of the RCM approach established by ABS.

3.6.1 Identify Operating Mode and Operating Context

The operation of a system is necessary to achieve the goals and meet the needs set by the system. This process involves identifying desired functions and performance at various levels. Cooling and compressed air system operating modes refer to the ship conditions that the shipowner is expected to meet on a daily basis, in all modes of operation. There are four operating modes distinguished:

1. Operating mode at full speed (when sailing at sea).
2. Operation mode in congested areas (when sailing in areas with heavy ship traffic).
3. Maneuvering operating mode (when performing maneuvers on the side).
4. Loading and unloading operation mode (when carrying out the cargo handling process).

The context of ship operations is the conditions in which the system is expected to operate according to established specifications. The operating context must be able to explain:

1. The physical environment in which a functional group operates.
2. Description of the use of functional groups.
3. The performance capabilities assigned to the functional groups, as well as the required performance of each additional integrated functional group.

There are several things that need to be considered when wanting to create an operational context, namely:

a. Serial Redundancy: Equipped with identical standby systems or equipment to support functional group operations. If the system experiences a failure, the standby system will be activated. The operating context for running systems and standby systems is different. Functional failures when the system is operating will be visible directly, while functional failures in standby conditions will be hidden.
b. Parallel Redundancy: Equipped with systems or equipment that operate simultaneously. Each system has the capability to meet overall demand. If one system fails, the other system can still operate, but with a higher capacity. In some designs, the standby system can also be a backup.
c. Performance and Quality Standards: Systems or equipment may be required to operate at certain performance levels or provide services of a certain quality.
d. Environmental Standards: To comply with international, national and local laws and regulations.
e. Safety Standards: Potential hazards in the context of operations and protective measures required to protect the crew.
f. Shift Arrangement: It is assumed that the ship's propulsion system operates continuously, except when docking. The ship's service electrical power also operates continuously. System setup and maintenance strategies must be carefully designed to ensure system reliability.

3.6.2 Identify Functional Failure and Failure Effect

In the context of this analysis, damage type refers to the failure of an element to fulfill its function. The impact of this damage often occurs in various ways, affecting not only functional elements but also the entire system. This stage helps in illustrating how the operation and functionality of the failed components are connected and interdependent with each other. In the FMECA process, all functional defects of components are identified by considering the effects of damage at higher system levels. This is done to evaluate the impact on overall system performance, so clear definitions of components and systems are essential. This stage is crucial for identifying performance achievements, effectiveness, input or output, overall results, speed, and other factors related to each function.

The next step in assessing the impact of failure on a component or system is to identify that impact on the block diagram of the propulsion cooling and compressed air system. The system block diagram is used to identify the relationships between system functions required by the cooling and compressed air to operate effectively. The output of each functional block will show the functions that must be present to carry out the overall system function relationship.

3.6.3 Determining Failure Mode

This analysis involves all processes or outputs that are expected to limit the causes of damage in general. FMECA is expected to be able to facilitate the identification process of a collection of other potential causes. The analysis process at this stage can use KMP. X damage report data. It is hoped that the FMECA analysis from this research will prevent similar failures from occurring in future operations. In addition, the results of this study can provide valuable treatment suggestions for PT. X.

3.6.4 Determining Impact Criteria (Consequence)

This stage relates to how serious the effects or consequences caused by the damage (failure mode) in general. This refers to the impact criteria set by PT. X. Table 3.1 shows an explanation of each severity level.

Level	Impact Category	Operations
		Ship Fleet (core operational)
1	Very Light	Ship Fleet disruption (outside of docking time) ≤ 1 Day (annually)
2	Mild	Ship Fleet disruption (outside docking time) > 1 Day to ≤ 3 Days (annually)
3	Medium	Ship Fleet disruption (outside of docking time) > 3 Days to ≤ 8 Days (annually)
4	High	Ship Fleet disruption (outside of docking time) > 8 Days s.d. ≤ 14 Days (annually)
5	Very High	Ship Fleet disruption (outside of docking time) > 14 Days (annually)

Table 3. 1 Severity Level

3.6.5 Assessing Likelihood Criteria

In this step, analyze the possible criteria which refer to the standards of PT. X. The following are the possible categories that shows an explanation of each likehood level.

Probability Rating	Probability	Frequency	Probability of Likelihood
1	Very Rare	Does not occur or 1 time a year	<10% probability of occurrence per period
2	Rarely Occurs	May occur 2 times a year	Probability of 10% to. 25% occur per period
3	Moderate (Occurs Occasionally)	May occur 3 to 4 times a year	Probability >25% to. 40% occur per period
4	Happens Often	May occur 5 to 6 times a year	Probability >40% to. 55% occur per period
5	Almost Certain to Occur	May occur more than 6 times a year	Probability of >55% occurring per period

Table 3. 2 Likelihood Level

3.6.7 Determining Critical Equipment

The results of this FMECA analysis include an assessment of the critical level of components based on the risks and impacts that occur if failure occurs. To prepare FMECA, several standards are needed, including impact criteria (Consequence), Likelihood Criteria and Risk Matrix set by PT. X.

3.6.8 Analyzing Failure Mode Risk Levels (Current Risk)

According to the American Bureau of Shipping, (2020) risk results from the frequency of occurrence of an event and the consequences of the outcome of that event. Risk is something we cannot avoid. However, we can control the risk itself. At this stage, a risk matrix is prepared, namely a table that describes the level of risk based on a combination of the level of consequences and frequency of failure.

Risk Group	Risk Level Score
Low	(1-5)
Low-Medium	(6-11)
Medium	(12-15)
Medium-High	(16-19)
High	(20-25)

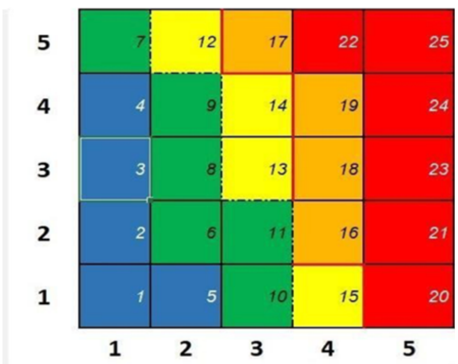

Figure 3. 3 PT. X Risk Matrix

Based on the risk matrix in Figure 3.3, the risk matrix can be converted into the following:

1. Low and low-medium risk groups are converted to low risk groups.
2. The medium risk group is converted to the medium risk group.
3. The medium-high and high risk groups are converted to the high risk

3.7 Maintenance Task Selection Analysis

In this step, the analysis refers to the task selection flow diagram presented in the ABS guide on Reliability-Centered Maintenance. The task selection flow diagram is used as analytical logic to select the most appropriate management strategy to overcome existing failures with the aim of preventing them.

3.7.1 First Selection Decision

This step is needed to determine whether the failure that occurs falls into the high or low risk category.

1. Highest risk

   Failurethose with high risk generally will not meet the criteria stated as acceptable by care management. In general, to meet these acceptable criteria, fundamental changes to the design and operation of the system are required.
2. Lowest risk

   Failures that have a very low risk are generally acceptable for most companies or organizations, and do not require advanced failure management strategies to handle them.
3. Confidence in the risk characterization

   Strong confidence in decisions regarding the level of failure risk shows that users are able to identify risk characteristics correctly and can manage them well. On the other hand, if this belief is not strong enough, further discussion or explanation needs to be carried out before continuing the RCM process. In general, risk levels are often initially conservatively classified as medium or moderate before undertaking further RCM processing.

3.7.2 Second Selection Decision

Condition monitoring is the main choice in determining the type of treatment to be carried out because of technical considerations and cost effectiveness. To determine whether failures can be managed through condition monitoring, the team must select specific tasks and determine appropriate time intervals for each task. The following are several criteria that need to be considered when making this decision

a. *Maintenance Task Selection Criteria*
   To determine whether condition monitoring is an appropriate action, it is important to ensure that it is feasible and effective. In evaluating its suitability and effectiveness, the following factors should be considered:
   1. It needs to be implemented practically, for example regarding the maintenance time

intervals required and accessibility to carry out maintenance activities must be operationally adequate.

2. Should have a high success rate in detecting failure modes.
3. It must be cost effective, which means the costs incurred for maintenance activities must be lower than the costs that would be incurred if a failure occurred.

b. Maintenance Task Interval Determination

Determining the ideal interval for maintenance actions ideally uses actual failure data. However, for most companies or organizations, this is not realistic. Therefore, the frequency of maintenance actions must be determined based on several sources ordered by priority and documented as follows:

1. Generic PF interval data
2. Recommendations from the manufacturer.
3. The maintenance action interval currently being performed.
4. The experience the team gained from the maintenance department

For maintenance actions using condition monitoring, maintenance time intervals must allow sufficient time to provide warning of possible failure. This allows adequate time to take action to prevent worse consequences. The interval of treatment measures should be set as less than half of the interval between anticipated initial signs of PF.

3.7.3 Third Selection Decision

The next step is to determine whether the failure mode that occurred is evident or hidden.

a. Evidence of Failures
   Evident failuresis a type of failure that will be clearly detected by the operational crew when carrying out work operations under normal conditions (NOC). An example is a decline in performance or function that will become apparent in the future without any time limit or incident occurring.
b. Hidden Failures
   Hidden failuresis a type of failure that is not immediately detected by the operational crew when carrying out operations under normal circumstances. Usually, hidden failures are revealed after a failure occurs or after several previous failures. For example, damage to a protection device

   causing operations to be unsafe is an example of a hidden failure.

Although hidden failure does not immediately cause visible consequences, it can increase the risk of multiple failures occurring. Factors such as security, safety, environmental, or operational implications should be carefully considered and noted as some of the possible impacts resulting from the failure. If the failure is hidden, and no condition monitoring maintenance action, planned maintenance, or a combination of several actions can reduce the risk to acceptable criteria, then the team must carry out a failure-finding task as steps to manage failure.

3.7.4 One-time Changes

If the failure is evident or hidden, and no failure-finding task can produce an acceptable level of failure risk, then it must be concluded that the risk cannot be reduced to a low risk level. Next, appropriate actions or combinations of several actions will be determined to manage the failures that occur. If it has been decided that the risk must be lower than can be achieved with maintenance measures, then consideration should be given to implementing one-time changes to manage the failure. In evaluating the effectiveness of a one-time replacement measure, the following points need to be considered

3.7.5 Maintenance Task Categories

The results of the RCM analysis in Determining and planning the allocation of maintenance tasks are divided into several categories based on location and party responsible for maintenance activities, including but not limited to:

a. Category A
   In this category, components can even be repaired or maintained (maintenance).when the ship is operating or sailing. The ship's crew can immediately carry out these maintenance activities.
b. Category B
   In this category, when a component enters the maintenance schedule or experiences damage or malfunction, the ship owner is required to carry out maintenance and repairs when the ship is not in operation, and the ship is placed in a shipyard equipped with repair facilities. The ship owner must also be accompanied by the vendor of the component during the maintenance process to ensure that maintenance activities comply with the component's standards.
c. Category C
   In this category, maintenance of ship components must be carried out when the ship is not operating. Maintenance is carried out at the shipyard and requires a docking process in an area without water (dry dock). Maintenance must be carried out using the repair and maintenance facilities available in the dry dock

3.7.6 Maintenance Task Interval

In determining and planning the allocation of maintenance tasks, there is the concept of task interval. Task interval is a time span or schedule when an operation or maintenance is carried out on each component. Task intervals derived from RCM analysis do not have to match maintenance schedules based on existing calendars. This needs to be adjusted to the existing maintenance schedule because the task interval can be shorter or longer than the predetermined schedule, depending on the following criteria:

a. Maintenance activities with significant occupational and environmental safety consequences if not carried out properly, the maintenance interval should be shorter than the existing maintenance schedule to ensure that the risk of component failure is small and does not endanger safety during operation.
b. Maintenance activities with the consequence of disrupting operations if not carried out correctly, then maintenance intervals can be shorter or longer than the existing maintenance schedule. However, if a decision is taken to schedule maintenance intervals

longer than the existing schedule, this must be approved by the responsible party in the company's maintenance department.

3.8 Web-Based

The use of web platforms to collect, process, and analyze research data. By utilizing web-based technologies, the data collection process becomes more efficient and accessible from various geographical locations, allowing for wider participation and faster responses from respondents. In addition, web-based platforms allow for real-time data analysis, so researchers can immediately see patterns and trends that emerge during the data collection process.

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CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Collection

The data obtained from PT. X was obtained in two ways. There are, observations in the field and retrieval of information data in the form of technical data, and other documentation related to the system of KMP. X ship data with ro-ro ferry type. These data can be explained as follows.

a. Field Observation

Observations are made to find out the maintenance system, namely how the company can overcome breakdowns with its maintenance methods.

b. Company data

1. Specification data, namely general specification data of the KMP. X ship to find out the specifications of the components installed on the tool
2. Operational and Repair Data. Data on damage, non-conformance, and repairs utilized to compile a list of potentially failing compressed air and cooling systems as well as their damage history to find out how often components are damaged
3. P&ID, the compressed air and cooling systems design data are utilized to ascertain the precise state of the cooling and compressed airand propulsion system as well as the ship's condition to see the system flow diagram contained

4.1.1 General Specification Data

The KMP. X Training Ship is a ship owned by the Angkutan Sungai, Danau dan Penyeberangan (PT. X).

Tabel 4.1 Ship Specification Data

Ship Name	: KMP. X
Type	: Ferry Ro-Ro
Year Built	: 2013
Classification	: BKI
Length (LOA)	: 109,40 m.
Breadth (B)	: 19,60 m.
Depth (H)	: 5,60 m.
Draft (T)	: 4,10 m.
Grosse Tonnage	: 5000 GT
Speed	: 15 Knots

Main Engine	: YANMAR 6N330-EW
Total Power	: 2 X 3500 HP / 2 x 2574 kW at 620 RPM

Figure 4. 1 KMP. X

(Source : Surya.co.id - Tribunnews.com)

4.1.2 System Desain Data

Every system used for an FMECA analysis needs to be specified. The ABS RCM book's instructions are used in this research to identify the system partitions.

4.1.2.1 Cooling System

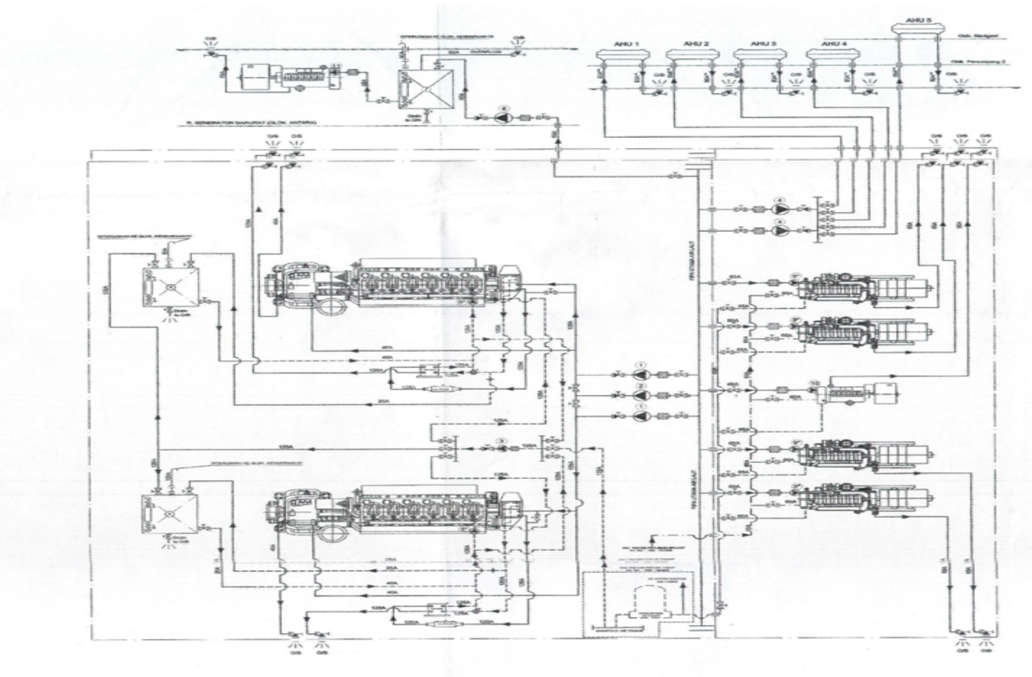

Figure 4. 2 P&ID of Cooling System KMP. X

(Source : Private Document)

To make it simpler to locate the components in the cooling system design on KMP. X, an asset register is conducted in the cooling system design drawing.Main Engine Open Loop System.

The following is a general explanation of the cooling system of the KMP ship. X.

a. Main Engine Open Loop System

The main engine open loop system is used to cool the ship's main engine using seawater. Seawater is drawn from the seawater circulating pump and circulated through the main engine heat exchanger. Inside the heat exchanger, the seawater absorbs heat from the main engine and is then discharged back into the sea.

b. Main Engine Close Loop System

The main engine close loop system is used to cool the ship's main engine using freshwater. Freshwater is drawn from the freshwater pump and circulated through the main engine heat exchanger. Inside the heat exchanger, the freshwater absorbs heat from the main engine and is then cooled by the seawater heat exchanger. The cooled freshwater is then circulated back to the main engine.

c. Emergency Generator System

The emergency generator system is used to provide electrical power during a blackout on the ship. The emergency generator is cooled using either an open loop system or a closed loop system.

d. Auxiliary Engine System

The auxiliary engine system is used to provide electrical power and hydraulic power for various purposes on the ship,such as water pumps, air compressors, and electric generators. Auxiliary engines are cooled using either an open loop system or a closed loop system.

e. Air Handling Unit System

The air handling unit system is used to provide fresh air and regulate the temperature and humidity of the air inside the ship. Fresh air is drawn from outside the ship and then filtered and cooled by the chiller. The cooled air is then circulated to the rooms inside the ship.

4.1.2.2 Compressed Air System

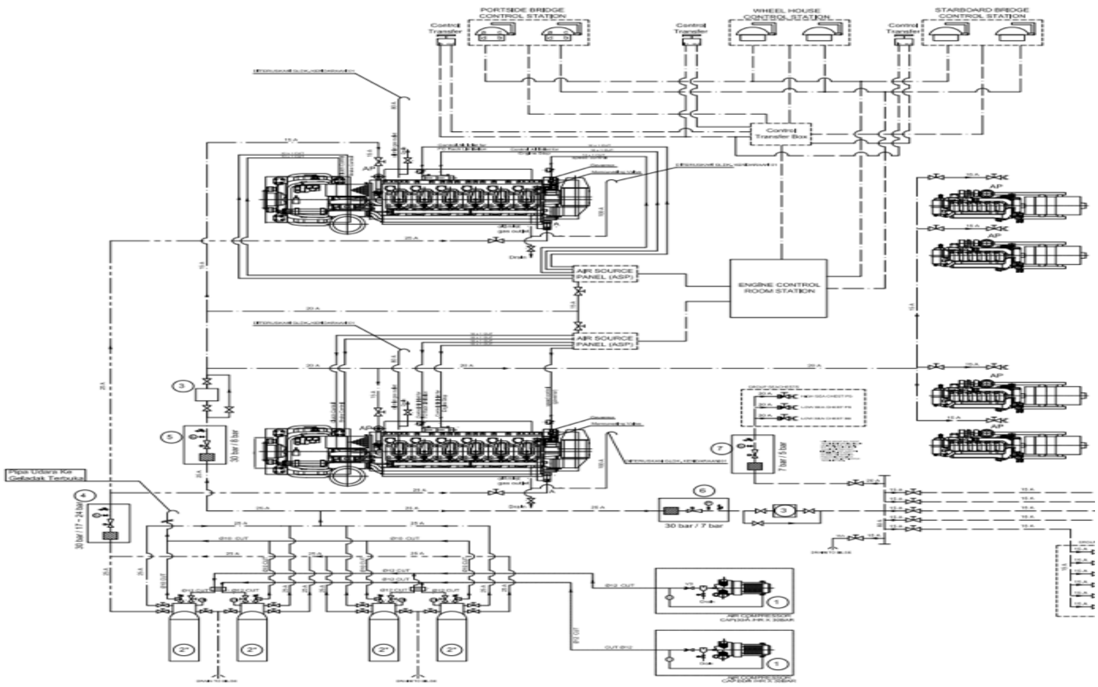

Figure 4. 3 Design of Compressed Air System KMP.X

(Source : Private Document)

The following is a general explanation of the compressed air system of the KMP ship. X.

a. Control and Service ME-Aux. Engine

This sub-system supplies compressed air for control and instrumentation purposes on the Main Engine (ME) and Auxiliary Engines (Aux. Engine). This air helps operate valves, actuators, and other pneumatic controls on these engines.

b. General Service

This sub-system provides compressed air for various applications across the ship, such as:

1) Blowing out pipes and tanks for cleaning
2) Operating pneumatic tools
3) Inflating life rafts and safety equipment

c. Group After Deck Equipment

This sub-system supplies compressed air for equipment located on the after deck, such as:

1) Deck winches
2) Cranes

4.1.3 Damage and Repair Data

One type of file record that can be acquired from PT. X is damage or non-conformity data. The information comprises past data regarding damage or nonconformance of the ship's current components, the KMP. X.The reason of system failure can be determined by analyzing damage information from historical repair data and repair/handling actions. If these malfunctions are not fixed right away, there could be more harm done and vessel operations stopped. As a result, FMECA analysis can utilize the damage that happens as input to identify failure modes and determine impact and likelihood criteria.

A. Jenis Ketidaksesuaian KAPAL	☑ Kerusakan	☐ Kecelakaan/Kejadian bahaya
	☐ Prosedur	☐ Pergantian
URAIAN :		
• Kondisi Tekanan pompa fresh water pump (FWP) menjadi tidak konstan / naik turun • Sehingga membuat Themperatur pendingin air tawar ME naik hingga over heating dan berakibat fatal.		
B. Penyebab.		
• Masuknya udara dalam sirkulasi instalasi tersebut yg membuat air pendingin tidak bekerja optimal • Masih dalam analisa (terjadinya kerusakan pada komponen pompa FWP)		
C. 1. Tindakan Penanganan.	Kondisi Alat Produksi	
• Menurunkan putaran mesin ketika tekanan pompa turun / hilang • Membuang udara dengan mencerat air pada exchanger hingga tekanan pompa naik kembali	☑ Beroperasi	
	☐ Tidak beroperasi	
2. Waktu Pelaksanaan : 04 – 06 Juni 2023		
D. 1. Usulan Penanganan Lebih Lanjut		
• Mengusulkan untuk diadakan pengecekan pompa dan memperbaiki kendala yang terjadi		

Figure 4. 4 Damage and Repair Data on 2018

4.2 System Partition

The relevant operating modes and operating circumstances should be mentioned when identifying functions. Rather than design capabilities, performance criteria should specify the lowest acceptable requirements for the operational context. There are two categories of performance standards: major functions and subsidiary functions. List of every function that has been found to have failed for every functional group, system, and component. Verbs, objects, and functional deviations are all present in any functional failure.

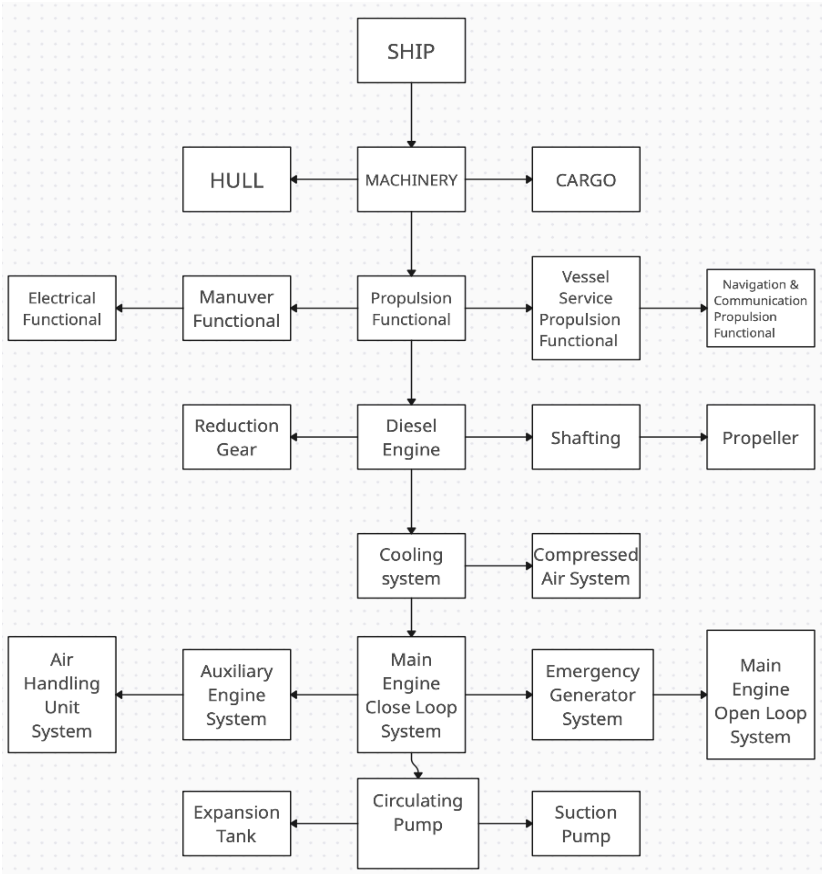

Figure 4. 5 Partitioning of Functional Groups

The ship's functional groups are categorized into four main areas:

a. Propulsion Functional Group

This group encompasses the systems responsible for generating and transmitting power to propel the vessel forward, including the main engine, propulsion cooling and compressed airing, and propellers.

b. Maneuvering Functional Group

This group comprises the systems that enable the ship to control its direction and maintain its position, including the rudder, steering gear, and thruster systems.

c. Electrical Functional Group

This group encompasses the systems that generate, distribute, and utilize electrical power for various onboard functions, including the main generators, switchboards, and electrical motors.

d. Vessel Service Functional Group

This group consists of the systems that provide essential services for the operation and support of the ship, including the compressed air system, cooling system, fire protection system, and bilge pumping system.

Table 4. 1 Partitioning of Compressed Air System and Cooling System

Propulsion Function Group		
	Diesel Engine	
		Basic Diesel Engine 01
		Basic Diesel Engine 02
		Fuel Oil System
		Lubricating Oil System
		Cooling System
		Compressed Air System
	Cooling and compressed airand Cooling and compressed airing	
		Propeller
		Cooling and compressed airing
	Reduction Gear	
		Main Engine Gearbox
		Lube Oil Transfer System

This system breakdown structure organizes the various components onboard the KMP. X (Level 1: Ship) into a detailed hierarchical format, focusing specifically on the Machinery and Utility Unit (Level 2).

Here's a breakdown of each level:

a. Level 3 (Functional Group)

This level categorizes the broad functions within the Machinery and Utility Unit.Examples might include:

b. Level 4 (System), Each functional group is further broken down into individual systems. For example, the Propulsion Function Group might contain:

1. Main Engine System: Includes the main engine itself, its starting system, and lubrication system.
2. Cooling and compressed airing System: Consists of the cooling and compressed air, bearings, and seals.

c. Level 5 (SubSystem) and Level 6 (Sub-SubSystem)

These levels provide even finer detail for complex systems.For example, the Main Engine System (Level 4) might be further divided into:

d. Level 7 Equipment (Parents) and Level 8 Equipment (Childs)

These levels identify the core components (Level 7) and their supporting parts (Level 8) within a system or subsystem.

e. Level 9 (Main Part/ Componen)

This is the most granular level, detailing the individual parts that make up the equipment. Examples might be "Piston Rings" or "Connecting Rods" within the Main Engine.

4.3 Asset Register

The asset register for the cooling system and compressed air system aboard KMP. X is an essential and detailed database that encompasses all relevant assets associated with these systems. For the cooling system, the register meticulously documents every component, including their technical specifications, installation dates, maintenance history, and operational performance metrics. This comprehensive record enables ship managers to monitor the efficiency and functionality of each component closely. By having access to detailed and up-to-date information, managers can identify potential issues before they escalate, plan for necessary repairs, and schedule replacements strategically. This proactive approach ensures that the cooling system remains in optimal condition, minimizing the risk of unexpected failures and maintaining the system's overall reliability. Similarly, the asset register for the compressed air system provides a thorough account of all related components, including compressors, dryers, filters, and storage tanks. Detailed records in the asset register include the performance parameters of each component, historical maintenance data, and any modifications or upgrades performed. This structured approach facilitates effective tracking of the system's operational status and aids in the timely execution of preventive maintenance tasks.

With accurate and readily available data, ship managers can enhance the operational readiness of the compressed air system, ensuring that it performs efficiently and reliably. This meticulous documentation supports the vessel's operational continuity and contributes to the smooth execution of onboard processes, thereby optimizing overall vessel performance and safety. Furthermore, the asset register supports regulatory compliance and safety protocols by documenting adherence to industry standards and regulations. For both systems, the register includes information on compliance with safety and environmental standards, such as those related to emissions and noise levels for the cooling system, and air quality and pressure safety standards for the compressed air system. This documentation ensures that all components meet required safety and environmental regulations, helping to avoid fines and penalties, and maintain operational certification.

Table 4. 2 Asset Register Cooling System

Level 5 SubSystem	Level 6 Sub-SubSystem	Level 7 Equipment	Name of Equipment
Cooling System			
	Main Engine Open Loop System		
		CO-CIP-01	Circulating Pump
			CO-CIP-01-Pump casing
			CO-CIP-01-Impeller
			CO-CIP-01-Bearing
			CO-CIP-01-Shaft seal cover
			CO-CIP-01-Shaft
		CO-CIP-02	Circulating Pump
			CO-CIP-02-Pump casing
			CO-CIP-02-Impeller
			CO-CIP-02-Bearing
			CO-CIP-02-Shaft seal cover
			CO-CIP-02-Shaft
		CO-CIP-03	Circulating Pump
			CO-CIP-03-Pump casing
			CO-CIP-03-Impeller
			CO-CIP-03-Bearing
			CO-CIP-03-Shaft seal cover
			CO-CIP-03-Shaft
	Main Engine Close Loop System		
		CO-CIP-04	Circulating Pump
			CO-CIP-04-Pump casing
			CO-CIP-04-Impeller
			CO-CIP-04-Bearing
			CO-CIP-04-Shaft seal cover
			CO-CIP-04-Shaft
		CO-EXT01	Expansion Tank
		CO-EXT02	Expansion Tank
		CO-SP-01	Suction Pump
			CO-SP-01-Pump casing
			CO-SP-01-Impeller
			CO-SP-01-Bearing
			CO-SP-01-Shaft seal cover
			CO-SP-01-Shaft
		CO-SP-02	Suction Pump
			CO-SP-02-Pump casing
			CO-SP-02-Impeller
			CO-SP-02-Bearing
			CO-SP-02-Shaft seal cover
			CO-SP-02-Shaft

Table 4. 3 Asset Register Compressed Air System

Level 5 SubSystem	Level 6 Sub-SubSystem	Level 7 Equipment	Name of Equipment
		CA-AR-02	Air Receiver
			CA-AR-01-Tank
			CA-AR-01-Inlet and Outlet
			CA-AR-01-Pressure Gauge
			CA-AR-01-Pressure Relief Valve
			CA-AR-01-Drain Valve
		CA-AR-03	Air Receiver
			CA-AR-01-Tank
			CA-AR-01-Inlet and Outlet
			CA-AR-01-Pressure Gauge
			CA-AR-01-Pressure Relief Valve
			CA-AR-01-Drain Valve
		CA-AR-04	Air Receiver
			CA-AR-01-Tank
			CA-AR-01-Inlet and Outlet
			CA-AR-01-Pressure Gauge
			CA-AR-01-Pressure Relief Valve
		CA-AS-01	Air Separator
		CA-AS-02	Air Separator
Compressed Air System			
	Starting Main Engine		
		CA-AC-01	Air Compressor
			CA-AC-01-Air filter
			CA-AC-01-Inlet valve
			CA-AC-01-Cylinder
			CA-AC-01-Piston
			CA-AC-01-Piston rings
			CA-AC-01-Connecting rod
			CA-AC-01-Flywheel
			CA-AC-01-Crankshaft
		CA-AC-02	Air Compressor
			CA-AC-02-Air filter
			CA-AC-02-Inlet valve
			CA-AC-02-Cylinder
			CA-AC-02-Piston
			CA-AC-02-Piston rings
			CA-AC-02-Connecting rod
			CA-AC-02-Flywheel
			CA-AC-02-Crankshaft
		CA-AR-01	Air Receiver
			CA-AR-01-Tank
			CA-AR-01-Inlet and Outlet
			CA-AR-01-Pressure Gauge
			CA-AR-01-Pressure Relief Valve

4.4 FMECA Analysis

FMECA (Failure Modes, Effects, and Criticality Analysis) for the compressed air and cooling systems on a ship is a method used to identify potential failure modes, their effects on the systems, and their criticality. In the compressed air system, FMECA helps pinpoint potential failure points such as air filters, inlet valves, and other components, assessing their impact on system efficiency and operational safety. For the cooling system, FMECA evaluates possible failures in elements like cooling pumps, radiators, and thermostats, and their effects on operational temperatures and engine performance. By assessing the impact and likelihood of failures, FMECA enables better maintenance prioritization and risk mitigation, ensuring system reliability and ship safety.

4.4.1 Operation Mode and Operating Context

Different operating modes need to be determined in order to ascertain the operational characteristics. To make the relationships between the functions of the chosen systems in the functional groups simpler to understand, block diagrams should be used to illustrate them in a narrative style. Every system that needs to be examined will have a list of failure modes created for it, taking into account its operational mode, performance or quality standards, environmental standards, safety standards, and system parameters. The following are the operations mode compressed air system and cooling system of KMP. X.

Table 4. 3 Operation Mode and Operating Context of KMP. X

Operating Context of Propulsion Functional Group	
The propulsion system consists of a low speed diesel engine with the brand Yanmar 6N330-EW NK 7781080 / FQS0147 with a maximum continuous rating (MCR) of 2,574 kW at 620 RPM, coupled directly to the cooling and compressed air supported by 2 intermediate bearings and two stern tube bearings and driving the cooling and compressed air-fixed pitch propeller.	
Common Characteristics	***Operating Mode***
	At Sea
Environmental Parameters	Air temperature: 27°C - 32°C Humidity: 62 - 90% Visibility: 7 km
Manner of Use	The propulsion system works from a speed of 0 knots to up to 15 knots with the ability to reverse direction and stop
Performance Capabilities	To get a performance of 2574 kW and engine speed of 620 RPM, control is carried out centrally in the wheelhouse
Common Characteristics	***Operating Mode***
	In Congested Waters
Environmental Parameters	Depends on geographical conditions and surrounding work environment
Manner of Use	The propulsion system works from a speed of 0 knots to up to 15 knots with the ability to reverse direction and stop

Performance Capabilities	To get a performance of 2574 kW and engine speed of 620 RPM, control is carried out centrally in the wheelhouse
Common Characteristics	***Operating Mode***
	Maneuvering Alongside
Environmental Parameters	Depends on geographical conditions and surrounding work environment
Manner of Use	The propulsion system works from a speed of 0 knots to up to 15 knots with the ability to reverse direction, stop and assist in the ship's mooring process
Performance Capabilities	To get a performance of 2574 kW and engine speed of 620 RPM, control is carried out centrally in the wheelhouse
Common Characteristics	***Operating Mode***
	Cargo Handil

4.4.2 Failure Mode Effects and Critically Analysis (FMECA)

The FMECA (Failure Modes, Effects, and Criticality Analysis) must provide a comprehensive overview of each failure mode by documenting all potential functional losses, the probability of each failure occurring, and the severity of its impact. This detailed assessment should include an evaluation of the associated risk for each failure mode, considering how each failure mode might lead to specific consequences. Particularly, when a failure mode directly results in a particular consequence, this direct relationship should be carefully analyzed and reflected in the consequence category of the FMECA. By doing so, the analysis ensures a thorough understanding of how each failure impacts the system, allowing for more accurate risk assessments and effective mitigation strategies.

4.4.3 Failure Functionality

The Failure functionality refers to the specific ways in which the component can fail to perform its intended function. This is done in order to identify any defects as well as the functions that the system's equipment or components have in relation to the ship owner's expectations.

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Circulate coolant throughout various components of the ship's cooling system, within specification Capacity 100 M3/H, Head 20m.	Primary	1.1	No pumping water to initiate coolant circulation (Total Failure)
			1.2	Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)

Figure 4. 6 Failure Functionality of Circulating Pump in Cooling System

4.4.4 Failure Mode Identification

One method of observing a failure is through a failure mode. Failure modes can have more than one cause, thus it's important to determine each failure mode's possible independent causes. Every type of failure has the potential to be lethal and to impair dependability, safety, and performance. Each failure mode's failure characteristics should be divided into three categories, such as wear-out failure, random failure, and wear-in failure.

Table 4. 4 Failure Mode on Circulating Pump

Failure Mode	
Impeller	Corroded
	Fractured
	Deformed
Bearing	Cracked
	Containinated
	Fractured
Casing	Deformed
	Fractured
	Corroded

4.4.5 Failure Effect

Each failure mode should be analyzed through three distinct effects: the local effect, functional failure, and end effect. The local effect refers to the immediate and direct impact of the failure mode on a specific part or component of the machinery, highlighting the initial malfunction or damage. This is followed by the functional failure, which describes how the local effect disrupts the overall functionality of the system or equipment, detailing the operational impact and any compromised performance. Finally, the end effect encompasses the broader consequences of the failure, illustrating the ultimate impact on the system's overall operation, efficiency, or safety, and the potential cascading effects that may occur if the failure is not addressed. Understanding each of these effects provides a comprehensive view of how a failure mode affects both the individual component and the larger system.

a. Local effect

Local Effect describes the initial change in equipment item or component operation when the failure mode occurs; the failure detection method, if any, should be identified and the availability of standby systems/equipment to provide the same function.

b. End Effect

End Effect describes the ultimate or final consequences of a failure mode if it were to go undetected and unaddressed. It represents the most severe or catastrophic outcome that could result from the failure. Identifying the end effects emphasizes the importance of preventive measures and early detection of failures to avoid catastrophic consequences.

4.4.5 Determining Impact Criteria (Consequence)

This stage assesses the seriousness of the effects or consequences resulting from damage or failure modes, reflecting the impact criteria established by PT. X. It involves evaluating how each failure mode affects overall system performance, safety, and operational efficiency. The severity levels, detailed in Table 3.1, categorize the potential consequences into different degrees of seriousness, ranging from minor to catastrophic. Each level is defined by specific criteria, such as the extent of operational disruption, safety risks, and financial impacts, providing a structured approach to understanding and addressing the significance of various failure modes within the system..

Level	Impact Category	Operations
		Ship Fleet (core operational)
1	Very Light	Ship Fleet disruption (outside of docking time) ≤ 1 Day (annually)
2	Mild	Ship Fleet disruption (outside docking time) > 1 Day to ≤ 3 Days (annually)
3	Medium	Ship Fleet disruption (outside of docking time) > 3 Days to ≤ 8 Days (annually)
4	High	Ship Fleet disruption (outside of docking time) > 8 Days s.d. ≤ 14 Days (annually)
5	Very High	Ship Fleet disruption (outside of docking time) > 14 Days (annually)

Tabel 4. 5 Severity Level

4.4.6 Assessing Likelihood Criteria

In this step, it is crucial to analyze the potential criteria based on PT. X's established standards. This involves categorizing and defining each likelihood level according to specific benchmarks set by the organization. The analysis should provide a detailed explanation of each likelihood level, which may include definitions ranging from "Highly Likely" to "Rare" or similar descriptors. Each category should be outlined with clear criteria that describe the probability of occurrence, incorporating factors such as historical data, operational conditions, and risk assessment standards. This detailed examination ensures that the criteria align with PT. X's standards and accurately reflect the potential risks associated with various likelihood levels.

Probability Rating	**Probability**	**Frequency**	**Probability of Likelihood**
1	Very Rare	Does not occur or 1 time a year	<10% probability of occurrence per period
2	Rarely Occurs	May occur 2 times a year	Probability of 10% to. 25% occur per period
3	Moderate (Occurs Occasionally)	May occur 3 to 4 times a year	Probability >25% to. 40% occur per period
4	Happens Often	May occur 5 to 6 times a year	Probability >40% to. 55% occur per period
5	Almost Certain to Occur	May occur more than 6 times a year	Probability of >55% occurring per period

Table 4.8 Likelihood Level

4.4.7 Criticality Level

Table 4. 6 PT.PT. X Risk Level

Risk Group	Risk Level Score
Low	(1-5)
Low-Medium	(6-11)
Medium	(12-15)
Medium-High	(16-19)
High	(20-25)

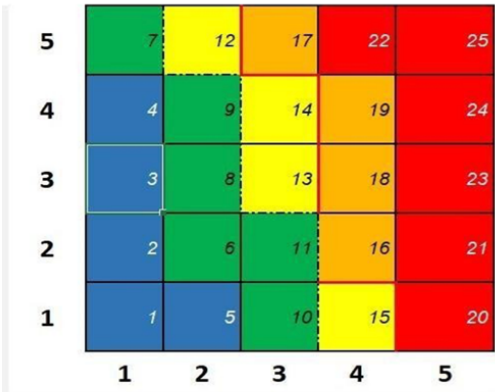

Figure 4. 7 PT. X Risk Matrix

Based on the risk matrix in Figure 3.3, the risk matrix can be converted into the following:

1. Low and low-medium risk groups are converted to low risk groups.
2. The medium risk group is converted to the medium risk group.
3. The medium-high and high risk groups are converted to the high risk

PT. X's risk matrix is used to determine the degree or consequence criterion, the likelihood criteria, and the risk matrix employed in this FMECA analysis. The severity of each failure mode in FMECA analysis can be assessed quantitatively or qualitatively. To assess severity, this study employs a qualitative approach. Qualitative methods can be used to determine the chance of failure when quantitative data, such as component reliability statistics, is unavailable. As a result, engineering decisions can be made in its application based on previous damage history data. If the qualitative method is utilized, it is important to establish the severity categorization, probability of occurrence, and risk matrix. After determining the outcome and likelihood, convert value to the risk matrix.

4.5 Maintenance Task Allocation and Planing

Maintenance tasks can be identified in each step organized according to several categories:

a. Category A
   Can be performed on site (at sea, offshore) by on-site mechanical personnel.
b. Category B
   Must be performed concurrently by equipment vendors or onshore facilities.
c. Category C
   Must be performed at the shipyard.

In this research, the ABS Rules standard and its associated logic tree analysis form the foundation for the proposed activities. This approach ensures a structured methodology for addressing failure modes. To effectively determine the appropriate actions for each failure mode, it is crucial to utilize comprehensive supporting documentation, including company journals, technical books, research papers, and nonconformity records. These resources provide the necessary context and data to inform the decision-making process. Based on the insights gained from the planning analysis and the allocation of maintenance tasks, a detailed summary of maintenance jobs will be compiled. This summary will outline the recommended actions and strategies for each identified failure mode, thereby ensuring a systematic and well-documented approach to maintenance planning and execution.

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4) Current	Risk (4) Projected	Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
perform detailed visual inspections of the pump casing and make temporary repairs to any detected flaws using onboard materials.	CM	3.1 3.2	Low	Low	1000 hours and/or Performed on: Regular maintenance inspection When flaws are detected	-	Follow recommended inspection procedures carefully to detect any damage
assess the impeller for corrosion damage and, if necessary, replace it with a spare corrosion-resistant impeller available onboard.	CM/PM	4.1 4.2	Low-Medium	Low-Medium	1500 hours and/or Performed on: Regular maintenance inspection When corrosion damage is detected	-	Conducted by a technician with special attention to corrosion damage
immediately replace the fractured impeller with a spare one and check for any additional damage to the pump system.	FF	5.1 5.2	Low-Medium	Low-Medium	When damage occurs Performed on: Detection of impeller fracture	-	Replace the fractured impeller promptly and conduct a thorough check for any additional damage.

Figure 4. 8 Summary Category of Maintenance Task of Bearing in Cooling System

The goal of selecting an appropriate maintenance strategy is to ensure that maintenance decisions and actions are both effective and efficient in addressing identified failure modes. To achieve this, each proposed action for managing the failure modes, as identified through Failure Modes, Effects, and Criticality Analysis (FMECA), will be categorized into specific maintenance types. These categories include One-Time Changes (OTC), Condition Monitoring (CM), Failure Finding (FF), and Preventive Maintenance (PM). OTC refers to modifications or upgrades made once to rectify a specific issue or enhance system performance permanently. CM involves regular monitoring of system conditions to detect early signs of potential failures. FF focuses on identifying hidden failures that may not be immediately apparent but could impact system reliability. PM includes routine maintenance tasks designed to prevent known issues from occurring.

To determine the most appropriate maintenance actions, a Logic Tree Analysis will be employed. This analytical tool helps in systematically evaluating each failure mode and its corresponding suggested actions, categorizing them based on the maintenance guidelines and tasks. The outcomes of this analysis will guide the selection of the most effective maintenance approach, ensuring that each type of maintenance is applied in a manner that aligns with its intended purpose and optimizes overall system reliability and performance. By using Logic Tree Analysis, the maintenance strategy can be refined to address specific needs and conditions, leading to more precise and successful maintenance interventions.

4.6 Compressed Air System Proposed Action Task Summary

Proposed action tasks for the Compressed Air System involve a thorough and systematic approach to maintaining key components to guarantee optimal performance and long-term reliability. For air compressors, routine maintenance and inspections are crucial for several critical components. These tasks include checking and replacing the air filter to ensure clean air intake, examining and servicing the inlet valve to prevent leaks and blockages, and inspecting the cylinder and piston for wear and tear. Additionally, maintenance of the piston rings and connecting rod is necessary to maintain proper sealing and alignment, while the flywheel and crankshaft require regular checks for balance and lubrication. Cooling systems must also be monitored to prevent overheating, and the compressor's performance should be evaluated to ensure it is operating within specified parameters. These measures help prevent breakdowns and maintain efficient operation, extending the lifespan of the compressors.

Similarly, maintenance tasks for air receivers focus on critical components to ensure system integrity and safety. Regular inspections and servicing of the receiver tank are essential to identify any signs of corrosion or structural issues. The inlet and outlet connections need to be checked for leaks and proper function to ensure effective air flow and pressure management. The pressure gauge must be calibrated and tested to provide accurate readings, while the pressure relief valve should be checked to ensure it functions correctly to prevent overpressurization. Additionally, the drain valve needs routine servicing to remove condensate that can lead to rust and system inefficiency. This comprehensive approach to maintaining both compressors and receivers aims to proactively address potential issues, ensuring that the compressed air system remains reliable, efficient, and safe throughout its operational lifecycle.

4.6.1 Category A

Table 4. 7 Category A Compressed Air System

Summary of Maintenance Category A	
Task Type	Quantity
PM	6
CM	2
CM/PM	6
OTC	1
FF	2
Total Task List	17

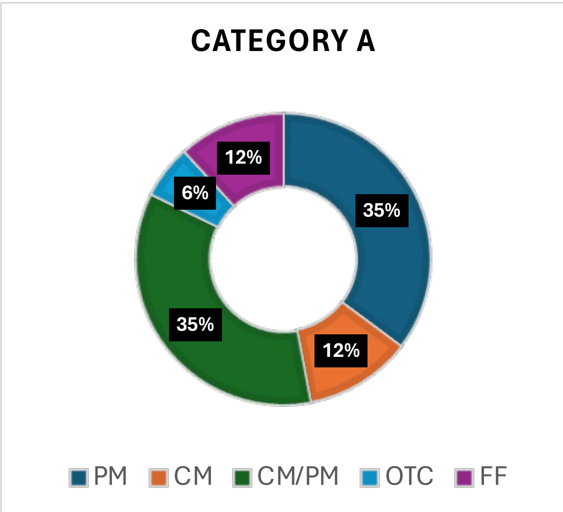

Figure 4. 9 Pie Chart of Category A Compressed Air System

Based on Figure 4.9, Category A illustrates a comprehensive maintenance strategy for the ship's compressed air system, with the largest share of activities allocated to Condition Monitoring (CM) and Planned Maintenance (PM), each comprising 35% of the total maintenance efforts. This balanced allocation underscores the dual emphasis on preventive measures and real-time health assessments. Planned Maintenance (PM) encompasses scheduled inspections and systematic preventive actions aimed at minimizing the risk of system failures by addressing potential issues before they escalate. Condition Monitoring (CM), accounting for 12%, involves continuous, real-time evaluation of equipment performance to detect early signs of wear or malfunction. Additionally, Failure Finding (FF) and One-time Changes (OTC) each represent 12% of the maintenance activities, highlighting the need for reactive maintenance strategies and specific adjustments to address unforeseen problems and ensure system reliability. This approach reflects a robust maintenance framework designed to enhance the operational integrity and longevity of the compressed air system.

4.6 2 Category B

Table 4. 8 Category B Compressed Air System

Summary of Maintenance Category B	
Task Type	Quantity
PM	2
CM	1
CM/PM	3
OTC	2
FF	1
Total Task List	9

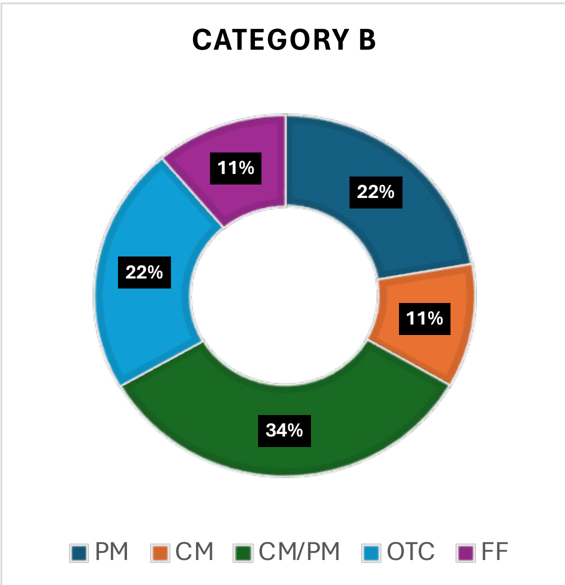

Figure 4. 10 Pie Chart of Category B Compressed Air System

Based on Figure 4.10, in Category B, Preventive Maintenance (PM), comprising 35% with 6 tasks, focuses on scheduled upkeep to prevent equipment failure. Corrective Maintenance (CM), representing 12% with 2 tasks, addresses repairs needed for existing damage or failures. A combined approach of Preventive and Corrective Maintenance (CM/PM) also constitutes 35% with 6 tasks, integrating both preventive and repair measures. Other Tasks (OTC), which make up 6% with 1 task, involve maintenance not classified under PM, CM, or CM/PM. Failure Found (FF), accounting for 12% with 2 tasks, deals with unexpected repairs for unforeseen issues.

4.6.3 Category C

Table 4. 9 Category C Compressed Air System

Summary of Maintenance Category C	
Task Type	Quantity
PM	5
CM	0
CM/PM	3
OTC	0
FF	0
Total Task List	8

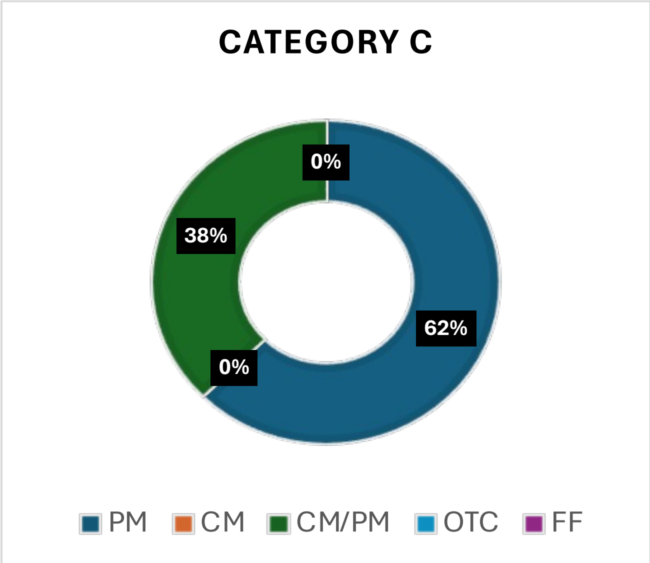

Figure 4. 11 Pie Chart of Category C Compressed Air System

Based on Figure 4.11, in Category C, Preventive Maintenance (PM) constitutes the predominant portion with 5 tasks, accounting for 63% of the total, underscoring its vital role in systematically performing scheduled upkeep to avert potential asset failures before they occur. In contrast, Corrective Maintenance (CM), which involves addressing and repairing issues after asset failures have manifested, is entirely absent in this category, represented by 0 tasks or 0%, highlighting a focus solely on preemptive measures. The Combination of Corrective and Preventive Maintenance (CM/PM) comprises 3 tasks, making up 38% of the total, reflecting an integrated approach that combines both preventive and corrective strategies to address and manage asset-related issues effectively. Other Tasks (OTC), which include miscellaneous maintenance activities not categorized under PM, CM, or CM/PM, are similarly not represented, with 0 tasks or 0%. Additionally, Failure Finding (FF), which entails identifying and rectifying unexpected asset failures, is also not included, indicated by 0 tasks or 0%, suggesting that the focus remains on planned preventive measures rather than reactive problem-solving.

4.6.4 Summary of Maintenance Category TAMBAH

Table 4. 10 Summary of Maintenance Category Compressed Air System

Summary of Maintenance Category	
Category	Failure Mode Quantity
A	17
B	9
C	10
Total Task List	36

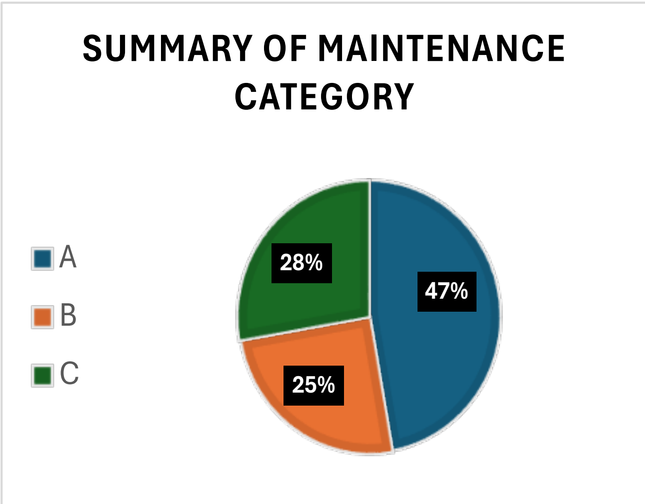

Figure 4. 12 Pie Chart of Summary of Maintenance Category Compressed Air System

Based on Figure 4.12, category A with the highest number of tasks at 17 (47% of the total), primarily involves routine checks, minor repairs, or adjustments to accessible components of the compressed air system, which the ship's crew can handle without external assistance. This frequency reflects the system's ongoing operational needs and the crew's ability to maintain basic system health, leading to a higher overall task count. Category B, with 9 tasks (25% of the total), requires specialized equipment or expertise typically found in shipyard environments, such as complex repairs, component replacements, or system overhauls demanding controlled conditions or specialized tools. This results in a lower frequency, indicating less frequent but critical maintenance needs. Category C, comprising 10 tasks (28% of the total), necessitates the most controlled environment, a dry dock, for major overhauls, inspections, or modifications requiring complete system accessibility and isolation from the marine environment. The relatively low number of such tasks reflects the infrequency of extensive work. Consequently, Category A not only has the most tasks but also the highest failure mode percentage at 47%, while Category B and C have failure mode percentages of 25% and 28%, respectively.

4.6.5 Summary of Task Type

Table 4. 11 Summary of Task Type Compressed Air System

Summary of Task Type	
Task Type	Quantity
PM	13
CM	3
CM/PM	12
OTC	3
FF	3
Total Task List	34

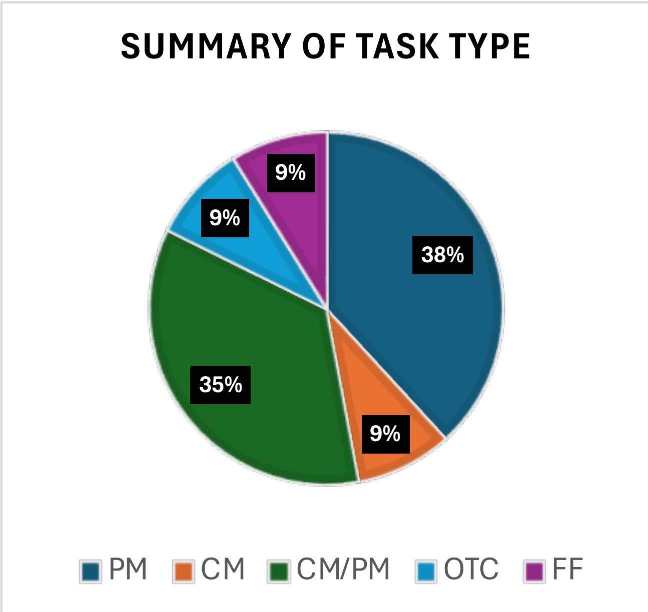

Figure 4. 13 Pie Chart of Summary Task Type Compressed Air System

Based on Figure 4.13, in Compressed Air System, Preventive Maintenance (PM) constitutes 38% of the tasks, totaling 13 tasks, which are performed regularly to prevent system failures and ensure ongoing reliability. Corrective Maintenance (CM) represents 9% with 3 tasks, focusing on repairs for failures that have already occurred. A combination of Preventive and Corrective Maintenance (CM/PM) accounts for 35% with 12 tasks, addressing both preventive and corrective needs. Other Tasks (OTC), making up 9% with 3 tasks, include maintenance activities that don't fit into the PM, CM, or CM/PM categories. Failure Found (FF) also comprises 9% with 3 tasks, targeting repairs for unexpected failures discovered during operation.

4.7 Cooling System Proposed Action Task Summary

In the proposed action plan for the cooling system, various components across different subsystems are identified for maintenance and inspection. For the Main Engine System, tasks include inspecting and servicing the circulating pump components—casing, impeller, bearing, cooling and compressed air seal cover, and cooling and compressed air—for three different pumps.

4.7.1 Category A

Table 4. 12 Summary of Category A Cooling System

Summary of Maintenance Category A	
Task Type	Quantity
PM	4
CM	4
CM/PM	8
OTC	1
FF	4
Total Task List	21

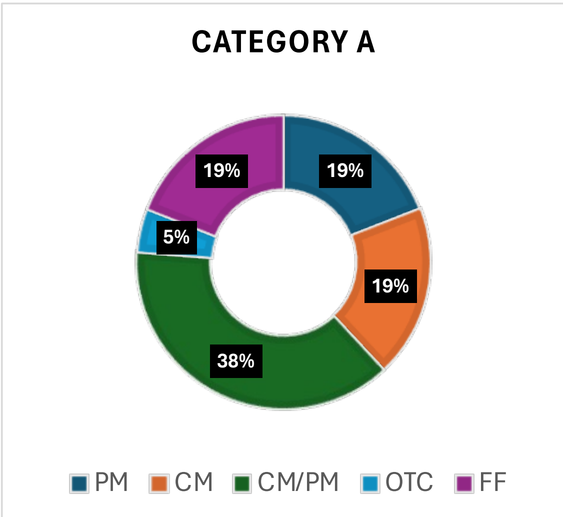

Figure 4. 14 Pie Chart of Summary Category A Cooling System

Based on Figure 4.14, in Category A, Preventive Maintenance (PM) comprises 19% of the tasks, focusing on regularly scheduled actions to prevent equipment failures or breakdowns. Corrective Maintenance (CM), also accounting for 19%, involves repairing failures or breakdowns that have already occurred. A significant portion, 38%, is dedicated to CM/PM, a combined approach that integrates both preventive and corrective measures. Other Tasks (OTC), representing 5%, include maintenance activities that do not fit into the PM, CM, or CM/PM categories. Failure Found (FF), which makes up 19% of the tasks, addresses repairs needed for failures or breakdowns discovered unexpectedly.

4.7.2 Category B

Table 4. 13 Summary of Category B Cooling System

Summary of Maintenance Category B	
Task Type	Quantity
PM	4
CM	4
CM/PM	7
OTC	0
FF	6
Total Task List	21

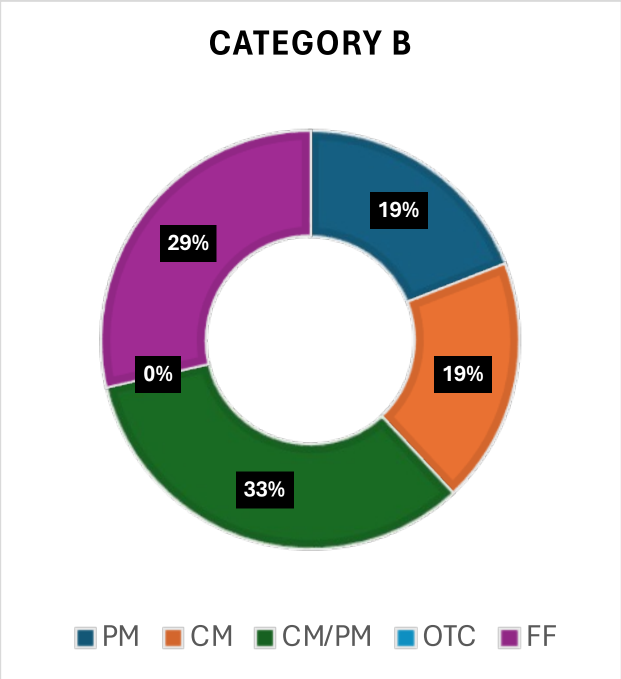

Figure 4. 15 Pie Chart of 1 Summary of Category B Cooling System

Based on Figure 4.15, in Category B maintenance tasks, totaling 21 in number, include 4 Planned Maintenance (PM) tasks (19%), 4 Condition Monitoring (CM) tasks (19%), 7 tasks involving a Combination of Corrective Maintenance and Planned Maintenance (CM/PM) (33%), and 6 Failure Finding (FF) tasks (29%). Notably, there are no One-time Changes (OTC) tasks (0%). The high percentage of CM/PM tasks reflects the need for a balanced approach, combining both preventive and corrective measures to ensure system reliability.

4.7.3 Category C

Table 4. 14 Summary of Category C Cooling System

Summary of Maintenance Category C	
Task Type	Quantity
PM	0
CM	0
CM/PM	5
OTC	1
FF	0
Total Task List	6

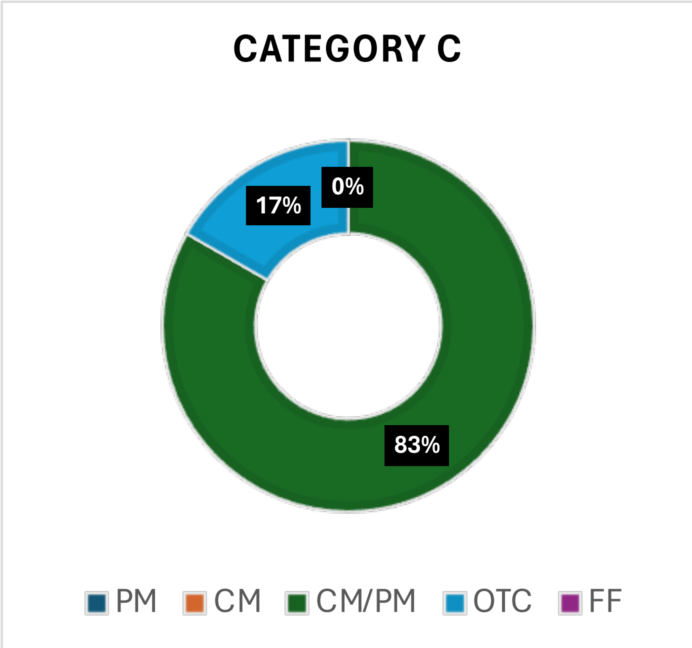

Figure 4. 16 Pie Chart of Summary Category C Cooling System

Based on Figure 4.16, in Category C, 5 tasks (83%) are allocated to a Combination of Corrective Maintenance and Planned Maintenance (CM/PM), which indicates a strong emphasis on both preventive measures and necessary repairs that can be managed by the onboard crew. This high proportion reflects the ship's focus on maintaining operational efficiency through a balanced approach to equipment upkeep. One task (17%) is dedicated to One-time Changes (OTC), suggesting occasional specific adjustments or modifications as needed. Notably, there are no tasks for Planned Maintenance (PM), Condition Monitoring (CM), or Failure Finding (FF), highlighting a reliance on reactive and combination maintenance strategies rather than scheduled checks or real-time health assessments. This distribution underscores the crew's capacity to handle most maintenance needs on location without external assistance, focusing on a mix of preventive and corrective actions.

4.7.4 Summary of Category

Table 4. 15 Summary of Category Cooling System

Summary of Maintenance Category	
Category	Failure Mode Quantity
A	21
B	23
C	4
Total Task List	48

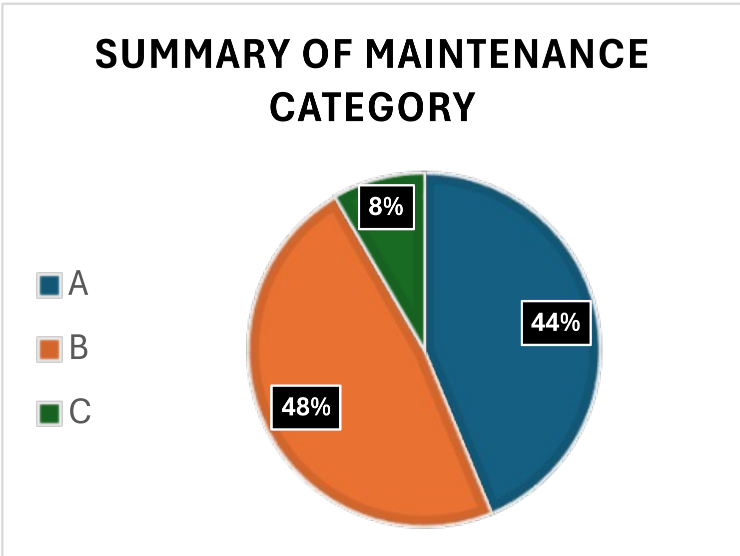

Figure 4. 17 Pie Chart of Summary of Category Cooling System

Based on Figure 4.17, Category A, with 21 tasks (44% of the total), includes routine checks, minor repairs, and adjustments to accessible components of the compressed air system, which can be handled on location by the ship's crew without external assistance. This high frequency underscores the system's ongoing operational needs and the crew's capability to maintain basic system health. Category B, comprising 23 tasks (48% of the total), requires specialized equipment or expertise typically found in shipyard environments, such as complex repairs, component replacements, or system overhauls that demand controlled conditions or specialized tools. This results in a higher task count but indicates less frequent, yet critical maintenance needs. Category C, with only 4 tasks (8% of the total), involves major overhauls, inspections, or modifications that necessitate the most controlled environment, such as a dry dock, reflecting the infrequency of such extensive work. Consequently, Category B has the highest task count, while Categories A and C have fewer tasks, highlighting varying levels of maintenance complexity and frequency.

4.7.5 Summary of Task Type

Table 4. 16 Summary of Task Type Cooling System

Summary of Task Type	
Task Type	Quantity
PM	8
CM	8
CM/PM	20
OTC	2
FF	10
Total Task List	48

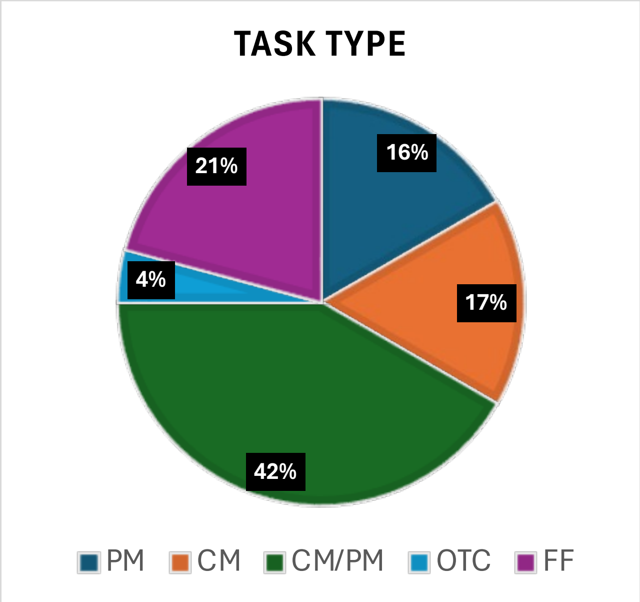

Figure 4. 18 Pie Chart of Summary Task Type Cooling System

Based on Figure 4.18, Category A, with the highest number of tasks at 21 (44% of the total), includes routine checks, minor repairs, and adjustments to accessible components of the compressed air system, which the ship's crew can manage on location without external assistance. This high percentage reflects the system's frequent operational needs and the crew's capability to handle basic maintenance tasks. Category B, comprising 23 tasks (48% of the total), demands specialized equipment or expertise, often found in shipyard environments, for complex repairs, component replacements, or system overhauls that require controlled conditions or specialized tools. This accounts for a significant portion of the maintenance tasks due to the critical nature and complexity of the work. Category C, with 4 tasks (8% of the total), involves major overhauls, inspections, or modifications that require a dry dock environment, emphasizing the infrequency and extensive nature of these tasks. Notably, there are no tasks under One-time Changes (OTC) or Failure Finding (FF), indicating that all maintenance activities fall into the routine or specialized categories described.

4.8 Cooling System and Compressed Air System

The proposed action task summary for the Cooling System and Compressed Air System highlights a strategic approach to optimizing maintenance activities. For the Cooling System, tasks are categorized into routine maintenance, such as regular inspections and minor repairs, as well as more complex operations requiring specialized tools and controlled conditions. This involves addressing frequent, on-site tasks and less frequent but critical interventions. Similarly, the Compressed Air System requires a balanced approach, focusing on preventive and corrective maintenance to ensure system reliability. This includes regular upkeep, specialized repairs, and major overhauls, reflecting the system's operational demands and maintenance needs. The proposed actions aim to streamline maintenance efforts by prioritizing tasks based on their complexity and frequency, thereby enhancing overall system efficiency and reliability.

4.8.1 Summary of Category

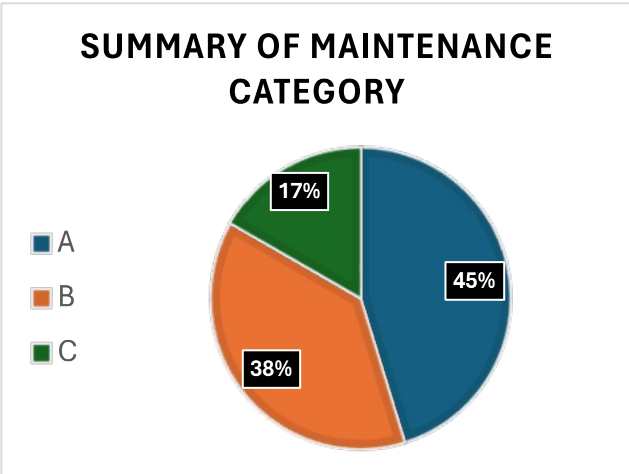

Figure 4. 19 Pie Chart of Summary of Category Cooling System and Compressed Air System

Based on Figure 4.19, Category A, comprising 38 tasks (45% of the total), encompasses routine maintenance activities such as regular inspections, minor repairs, and adjustments. These tasks are typically manageable on-site and often handled by the ship's crew, reflecting the system's continuous operational needs and the crew's ability to perform basic maintenance tasks. Category B, with 32 tasks (38% of the total), involves more complex maintenance requirements that necessitate specialized equipment or expertise, often found in shipyard environments. This category includes major repairs, component replacements, and system overhauls, indicating less frequent but critical maintenance needs that require controlled conditions or specialized tools. Category C, accounting for 14 tasks (17% of the total), involves extensive overhauls, thorough inspections, or significant modifications that demand highly controlled environments, such as dry docks. The lower number of tasks in Category C reflects the infrequency of such extensive work compared to Categories A and B. Overall, the data shows that Category A involves the highest number of tasks, Category B follows with a substantial number of tasks requiring specialized attention, and Category C has the fewest tasks, highlighting a gradient of maintenance complexity and frequency.4.8.2 Summary Task Type

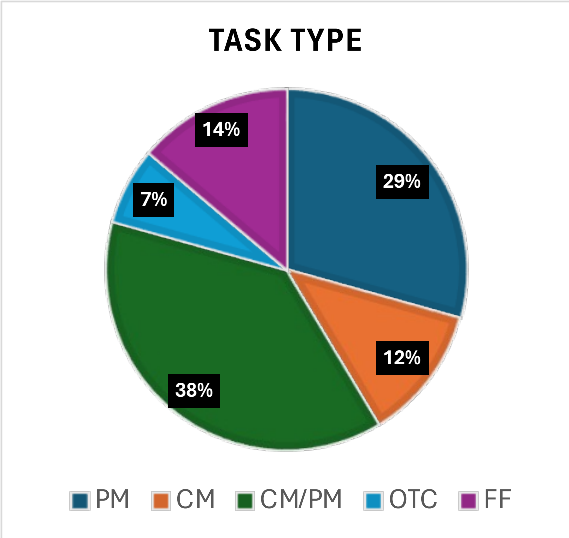

Figure 4. 20 Pie Chart of Summary Task Type Cooling System and Compressed Air System

Based on Figure 4.20, the distribution of task types reveals key insights into maintenance priorities. Preventive Maintenance (PM), with 34 tasks representing 29% of the total, plays a crucial role in regular upkeep and is the most frequently performed task type. This high percentage emphasizes the importance of ongoing maintenance to prevent potential issues. Condition Monitoring (CM) accounts for 14 tasks or 12%, focusing on regular checks and monitoring to assess system health and preemptively address issues. The combination of Corrective Maintenance and Planned Maintenance (CM/PM), with 44 tasks making up 38%, is the most significant category, highlighting the need for integrated approaches to both preventive and corrective actions. Other Tasks (OTC), comprising 8 tasks or 7%, cover less common maintenance activities, while Failure Finding (FF), with 16 tasks or 14%, deals with diagnosing and identifying failures. This distribution underscores the emphasis on integrated CM/PM approaches and highlights the balance between routine, monitoring, and diagnostic tasks essential for effective system maintenance.

4.9 Web-Based

The research results, following the specified stages, culminate in the identification of maintenance activity types. Once these types are determined, all FMECA analyses, conducted through the Reliability Centered Maintenance (RCM) approach, are consolidated into comprehensive summaries. These summaries detail the identified failure modes, their effects, criticality, and the proposed actions to mitigate risks. The consolidated data is then compiled into a digital record for each device, encompassing all relevant FMECA and RCM information. These digital records are subsequently made accessible online, enabling real-time updates, easy sharing, and streamlined management of maintenance activities. This approach ensures that all stakeholders have access to the latest maintenance data, facilitating proactive decision-making and enhancing overall system reliability and efficiency.

The results obtained in this research are as follows:

1) Mockup User Login Page

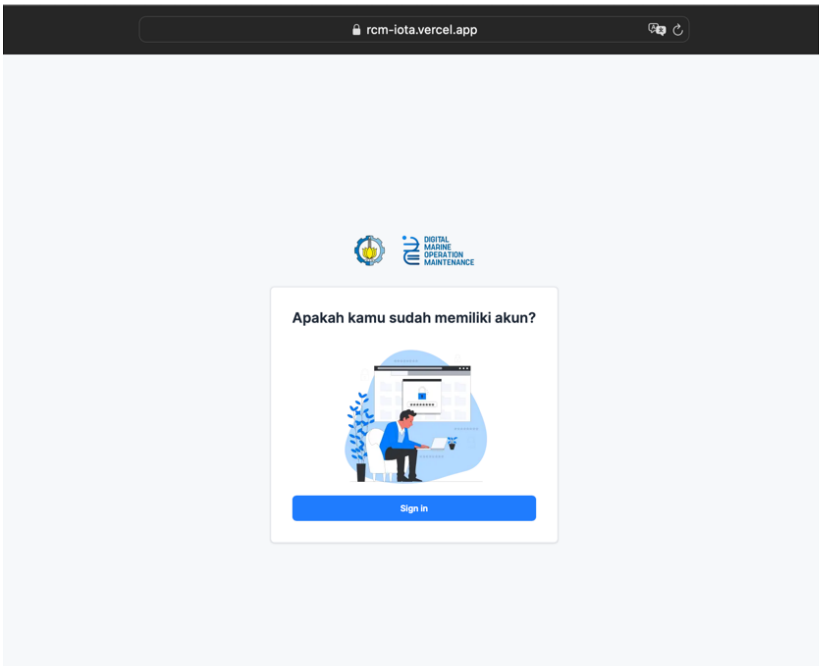

Figure 4. 21 Web Login

The screen in Figure 4.21 is designed to allow users to log in to their accounts using their email addresses and passwords.

2) Mockup Selection of the Component

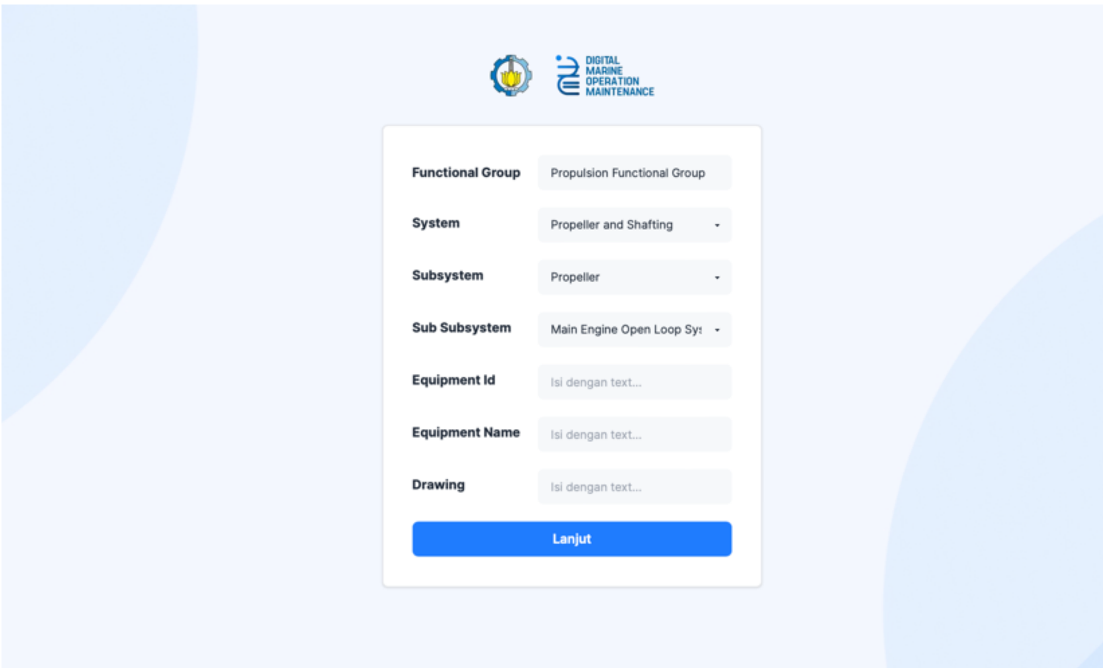

Figure 4. 22 Menu (Selection of the Component)

In Figure 4.22, there is a menu that contains options for selecting which components will be analyzed at each level sequentially so that they suit the selected system.

3) Mockup Failure Mode Selection

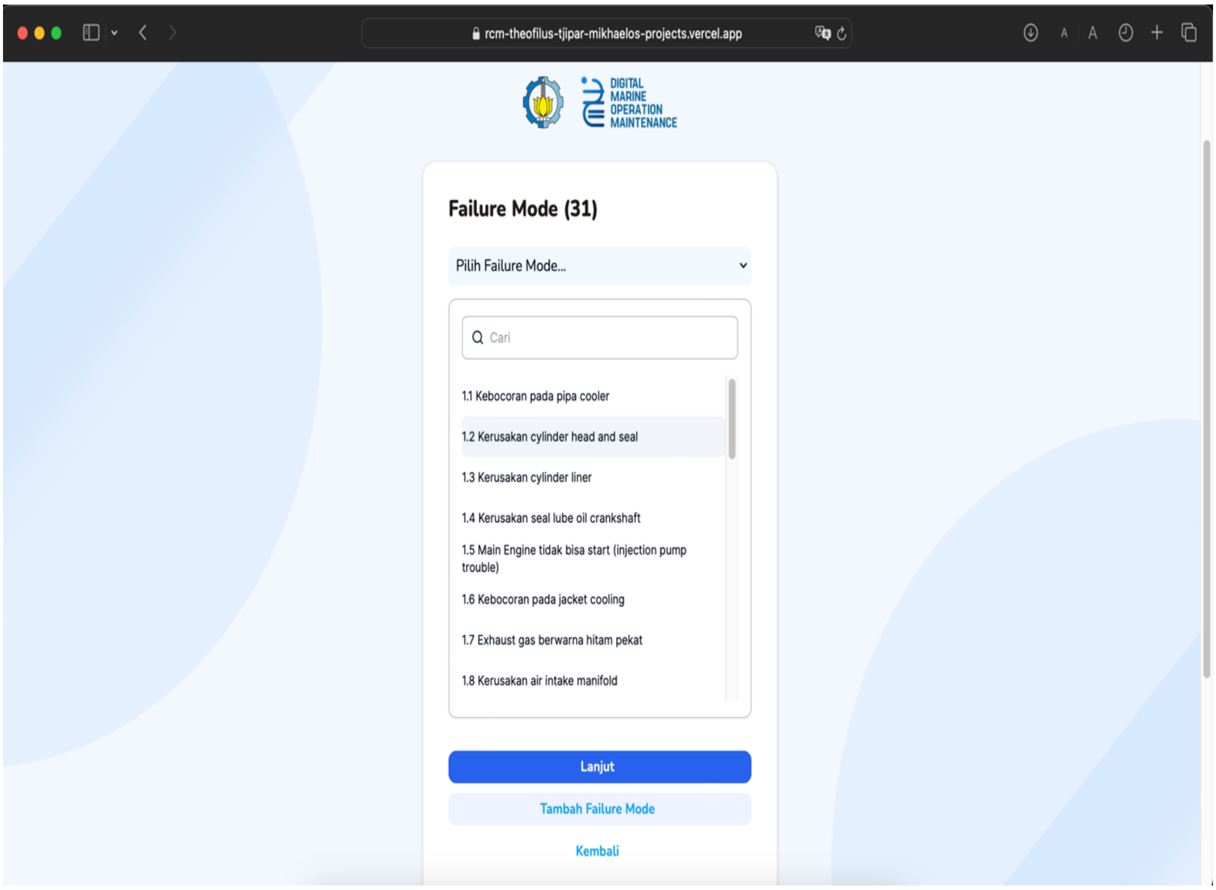

Figure 4. 23 Menu (Selection of the Failure Mode)

In Figure 4.23, the menu offers options for selecting the Failure Mode of the component being analyzed, focusing on system failure of a component. This approach details how the system operates and highlights the functional relationships between component failures. When applying FMECA, each functional failure of the component is thoroughly investigated by evaluating the consequences of the failure at the next higher system level. This assessment aims to understand the impact of each failure mode on the overall system performance. Therefore, it is crucial to fully specify both components and systems within this framework to ensure a comprehensive analysis. This involves detailing the interactions and dependencies between components, allowing for a precise identification of potential failure points and their cascading effects. This thorough specification ensures that the FMECA process accurately reflects the real-world operations and helps in developing effective mitigation strategies to enhance system reliability and performance.

4) Mockup Optional Analysis

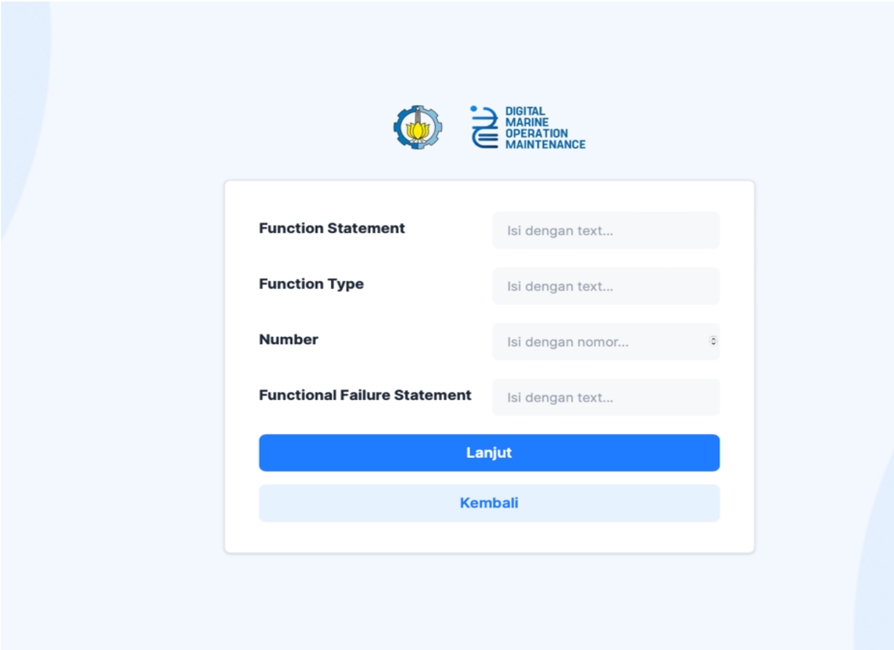

Figure 4. 24 Optional Analysis Step 1

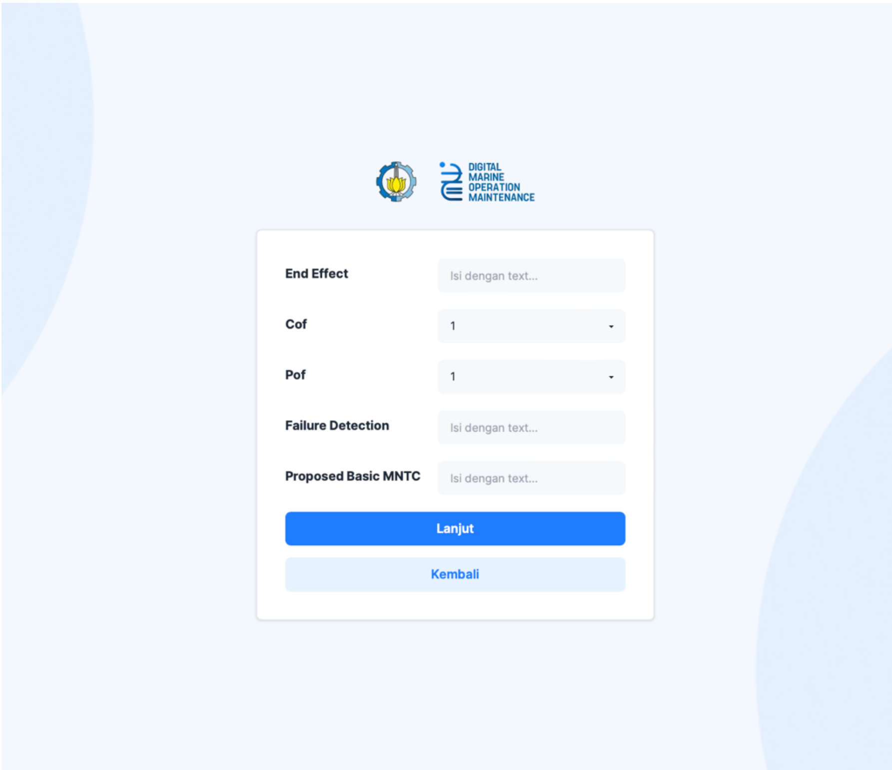

Figure 4. 25 Optional Analysis Step 2

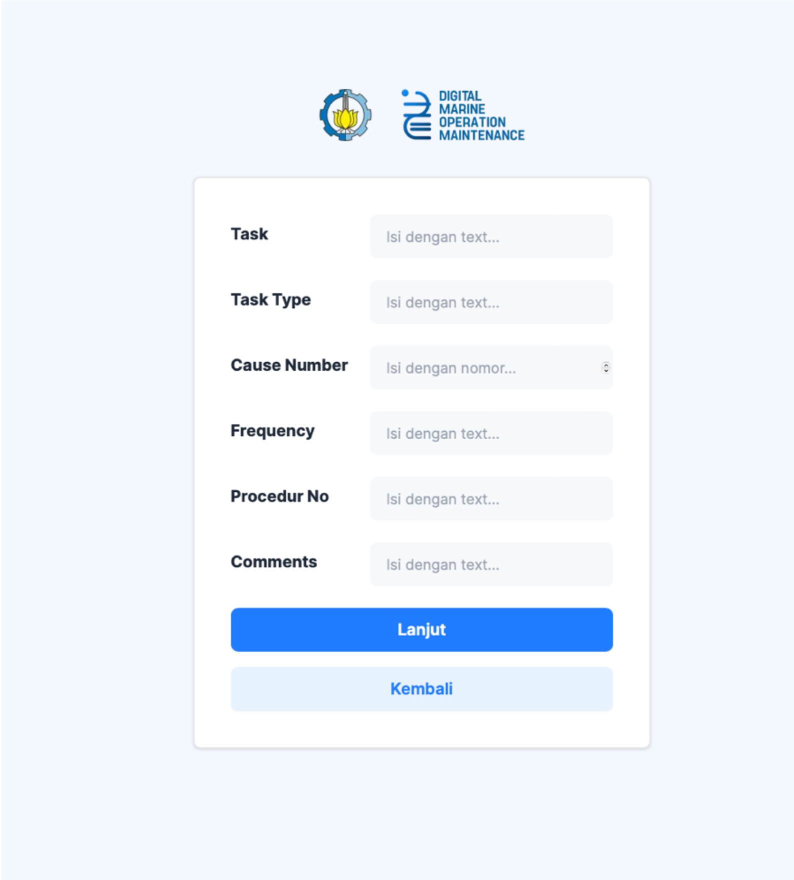

Figure 4. 26 Optional Analysis Step 3

Users can perform their own analysis depending on the components they wish to add to the system. This approach allows for tailoring the analysis to the unique needs of each component, ensuring a thorough evaluation to identify potential failures and maintenance requirements. The process involves data collection, condition monitoring, and risk assessment to determine the most effective maintenance actions. By conducting this analysis, users can develop more targeted and efficient maintenance strategies, enhancing the overall reliability and performance of the system.

This web platform can summarize the analysis already conducted and provide guidance for future development. By documenting the findings, users can track progress and changes in maintenance strategies, ensuring that each decision is based on accurate and up-to-date data. Additionally, the platform can serve as a collaborative tool, enabling various stakeholders to access information, share insights, and contribute to the development of sustainable maintenance strategies. In this way, users can ensure the system operates optimally, reduce the risk of failures, and improve operational efficiency.

1) Mockup Logic Tree

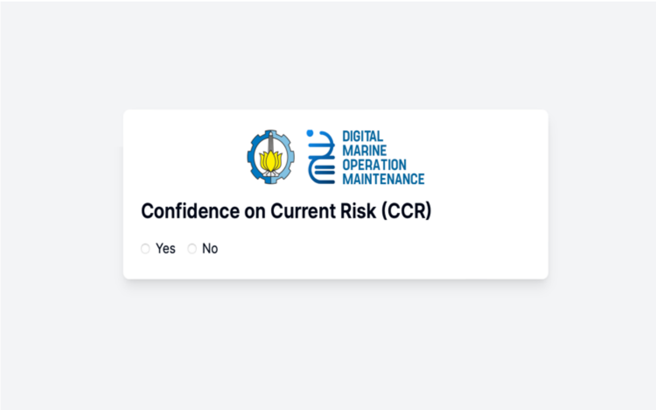

Figure 4. 27 Logic Tree Step 1

Figure 4. 28 Logic Tree Step 2

The web platform also provides a logic tree for determining the maintenance analysis tasks that need to be performed. This feature enables users to conduct their own logic tree analysis, allowing them to evaluate newly added components beyond the existing summaries. By using the logic tree, users can systematically break down complex maintenance issues into manageable tasks, identifying the root causes and necessary actions for each part of the system.

With the ability to perform their own logic tree analysis, users can ensure that each component is thoroughly examined and maintained according to its specific needs. This approach not only enhances the comprehensiveness of the maintenance strategy but also ensures that analysis can be continuously updated and refined. Users can dynamically adjust their maintenance plans as new components are added or as operational conditions change, maintaining optimal performance and reliability.

Furthermore, the logic tree tool facilitates a structured and methodical approach to maintenance planning, reducing the likelihood of oversight and improving decision-making. By documenting each step of the logic tree analysis, users can create a detailed record of their maintenance strategies, which can be referenced and modified as necessary. This continuous analysis and documentation process supports sustainable maintenance practices, enabling users to anticipate potential failures and address them proactively, thereby improving overall system efficiency and longevity.

2) Mockup of Function and Functional Failure and FMECA

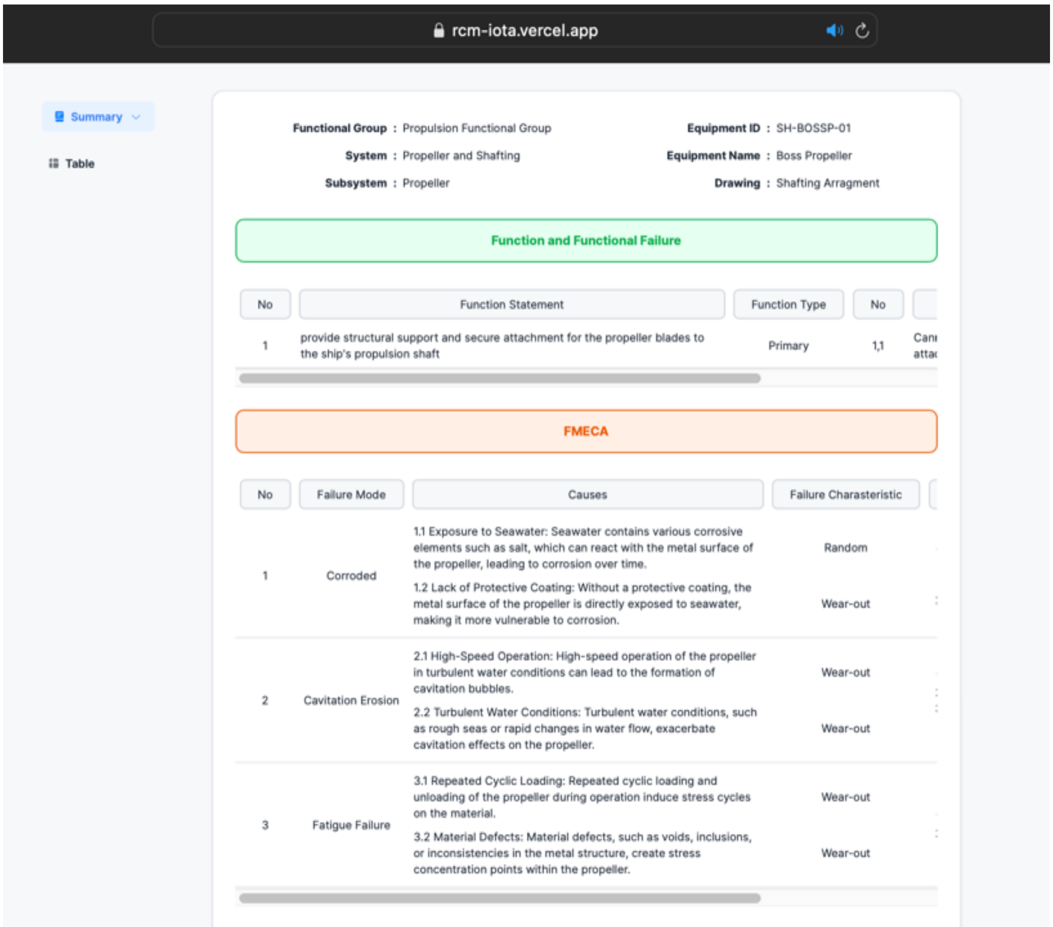

Figure 4. 29 Menu (Summary of Maintenance Task)

Based from Figure 4.24, the example menu below is identifies the following failure modes for the cooling and compressed air system:

- Wear
- Fatigue
- Overload
- Corrosion
- Erosion
- Cavitation

The menu concludes with a list of recommendations for preventing failures, such as using high-quality materials, proper design, correct manufacturing techniques, appropriate maintenance, and avoiding operational abuse. Using high-quality materials ensures durability and reduces the likelihood of component failure. Proper design ensures all components work harmoniously and efficiently. Correct manufacturing techniques guarantee components are made to the highest standards. Appropriate maintenance, including regular inspections and repairs, prevents issues before they arise. Avoiding operational abuse reduces unnecessary stress on the system. By following these recommendations, the risk of failures in the cooling and compressed air systems can be significantly reduced, thereby improving the overall reliability of the system and enabling better access and control via the web from anywhere.

3) Mockup of FMECA and Maintennace Task Selection

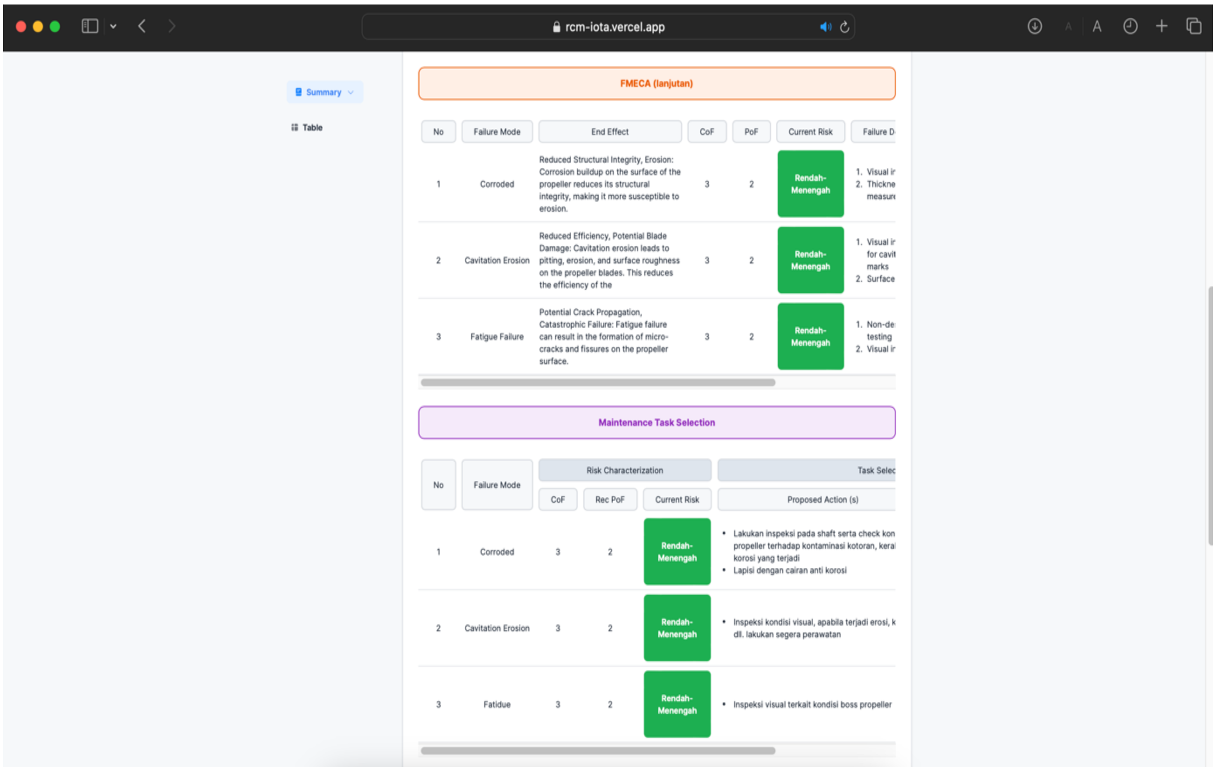

Figure 4. 30 Mockup of FMECA and Maintennace Task Selection

The Figure shows a list of tasks for the maintenance of a cooling and compressed air system. The tasks are prioritized based on their risk priority number (RPN). The tasks with the highest RPN should be addressed first.

The tasks in the list include:

- Inspect cooling and compressed air for cracks and wear: This task should be done regularly to identify any potential problems with the cooling and compressed air.
- Check cooling and compressed air alignment: This task should be done after any major work on the cooling and compressed air system to ensure that the cooling and compressed air is properly aligned.
- Lubricate cooling and compressed air bearings: This task should be done regularly to ensure that the bearings are properly lubricated and prevent wear.
- Inspect cooling and compressed air seals: This task should be done regularly to identify any leaks.

4) Mockup of Category

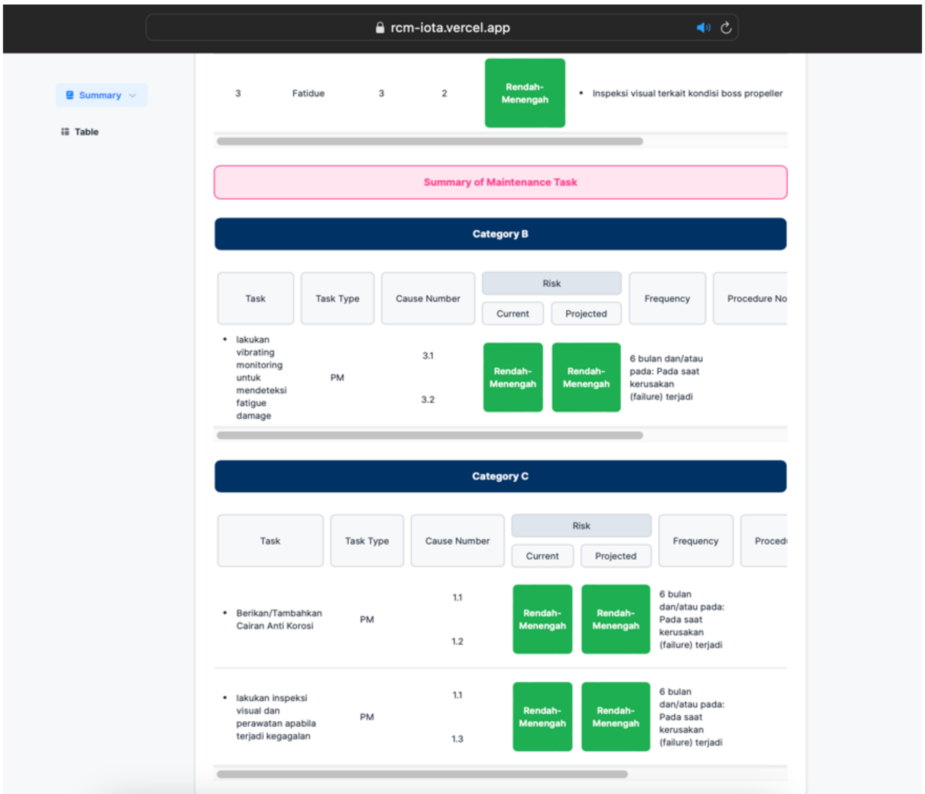

Figure 4. 31 Mockup of Category

The Summary of Maintennace Task for a cooling and compressed air system consists of several main steps:

1. Identify components: The first step is to identify all of the components in the cooling and compressed air system.
2. Identify failure modes: For each component, identify all of the potential failure modes. A failure mode is a way in which the component can fail.
3. Rate the effect of failure: For each failure mode, rate the effect it would have on the system. The effect of failure is the consequence of the component failing.
4. Rate the severity: For each failure mode, rate the severity of it. The severity is how serious the consequence of the component failing is.
5. Rate the probability of failure: For each failure mode, rate the probability of it occurring. The probability of failure is how likely it is that the component will fail.
6. Calculate the RPN (Risk Priority Number): Calculate the RPN for each failure mode. The RPN is the product of the severity, probability of failure, and effect of failure.
7. Prioritize the failure modes: Prioritize the failure modes based on their RPN values. The failure modes with the highest RPN values should be addressed first.
8. Develop preventive actions: Develop preventive actions to prevent the failure modes from occurring. Preventive actions could include redesigning the component, using better materials, or improving maintenance procedures

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CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The Reliability Centered repair (RCM) approach is applied in this study to establish the cooling system and compressed air system repair priorities. Repair history data from 2015 to 2024 as well as information from a number of other sources are used in the analysis process. The following outcomes were attained as a result of the planning analysis and maintenance work allocation:

1. In the Propeller System, there are a total of 36 failure modes distributed among three primary components: the Air Separator, which has 3 failure modes, the Air Compressor with 21 failure modes, and the Air Receiver, which accounts for 12 failure modes. Each component plays a crucial role in the overall operation, with the Air Separator responsible for separating air, the Air Compressor essential for compressing air, and the Air Receiver storing the compressed air. In contrast, the Cooling System is more complex, featuring 48 failure modes across several components. Specifically, the Air Handling Unit has 12 failure modes, reflecting its critical role in managing air flow and temperature. The Circulating Pump and Suction Pump each have 15 failure modes, indicating their significant roles in circulating and drawing fluids respectively. Additionally, the Expansion Tank and Daily Tank each have 3 failure modes, essential for handling fluid expansion and daily storage needs. This detailed breakdown underscores the importance of maintaining each component to ensure the smooth operation and reliability of both systems.
2. In the compressed air system, the current risk assessment reveals 21 instances classified as low risk, with the Air Separator contributing 3 instances, the Air Compressor 10 instances, and the Air Receiver 8 instances. Medium risk is identified in 15 instances, including 8 instances from the Air Compressor and 7 from the Air Receiver, indicating a moderate potential for issues that may need attention. Projected risk assessment anticipates a total of 23 instances, where the low-risk levels are spread as follows: 3 for the Air Separator, 11 for the Air Compressor, and 9 for the Air Receiver. In the cooling system, there are 18 instances of low risk distributed among components: Air Handling Unit with 3 instances, Circulating Pump and Suction Pump each with 4 instances, Expansion Tank with 3 instances, and Daily Tank with 3 instances. Medium risk totals 22 instances, with the Air Handling Unit accounting for 6 instances, and both the Circulating Pump and Suction Pump contributing 8 instances each. High risk is noted in 8 instances, divided equally between the Circulating Pump and Suction Pump, each having 4 instances. The projected risk for the cooling system amounts to 34 instances, with low-risk instances distributed as follows: 6 for the Air Handling Unit, 12 for the Circulating Pump, 12 for the Suction Pump, 2 for the Expansion Tank, and 2 for the Daily Tank, reflecting a potential increase in risk that warrants further monitoring and preventive measures.
3. There are 3 types of maintenance activities (task categories) in the cooling system and compressed air system analysis. For the cooling system, Category A has 21 task lists, Category B has 23 task lists, and Category C has 4 task lists. For the compressed air

system, Category A has 17 task lists, Category B has 9 task lists, and Category C has 10 task lists. In the cooling system, the total of 48 task lists is distributed as follows: Preventive Maintenance (PM) constitutes 17% with 8 tasks, Condition Monitoring (CM) also accounts for 17% with 8 tasks, and a Combination of Corrective Maintenance and Planned Maintenance (CM/PM) makes up 42% with 20 tasks. Other Tasks (OTC) and Failure Finding (FF) comprise 4% and 21%, respectively. In the compressed air system, there are 36 tasks distributed as Preventive Maintenance (PM) at 38% with 13 tasks, Condition Monitoring (CM) at 9% with 3 tasks, and a Combination of Corrective Maintenance and Planned Maintenance (CM/PM) at 35% with 12 tasks. Other Tasks (OTC) and Failure Finding (FF) each make up 9% with 3 tasks. The predominant maintenance type across both systems is a Combination of Corrective Maintenance and Planned Maintenance (CM/PM), indicating a strong emphasis on integrated preventive and corrective actions. This combined approach is the most significant in both systems due to its effectiveness in addressing a range of maintenance needs and ensuring system reliability.

5.2 Recommendation

The study's findings reveal that the data are incomplete, lacking essential details like asset registers and basic maintenance records. To increase the accuracy and effectiveness of future research, it's crucial to thoroughly document all component failures, provide detailed accounts of basic maintenance activities, perform in depth analyses of asset registers, and improve web-based systems to facilitate better data access.

1. Thorough Data Collection: It is essential to systematically document every instance of component failure across the entire fleet. This involves gathering detailed records of each failure event, including the nature of the fault, the affected component, and any contributing factors. By meticulously tracking this information, researchers can identify patterns and root causes more effectively, thus reducing the potential for errors and increasing the overall accuracy of the research findings.
2. Detailed Maintenance and Asset Analysis: To optimize maintenance practices, a comprehensive breakdown of basic maintenance procedures should be performed. This includes a detailed review of routine and preventive maintenance tasks, their frequencies, and their effectiveness. Additionally, an in-depth analysis of the asset register is necessary to assess the condition and performance of each component on the vessels. This analysis should identify any discrepancies or gaps in maintenance practices, allowing for the development of more targeted and efficient maintenance strategies.
3. Enhance Web-Based Systems: Upgrading the web-based systems used for data analysis is crucial for improving the accessibility and usability of research results. This includes implementing user-friendly interfaces, ensuring secure and reliable data storage, and providing tools for real-time data retrieval and analysis. By enhancing these systems, researchers can streamline their workflow, facilitate quicker decision-making, and ensure that all relevant data is easily accessible for ongoing and future analyses.

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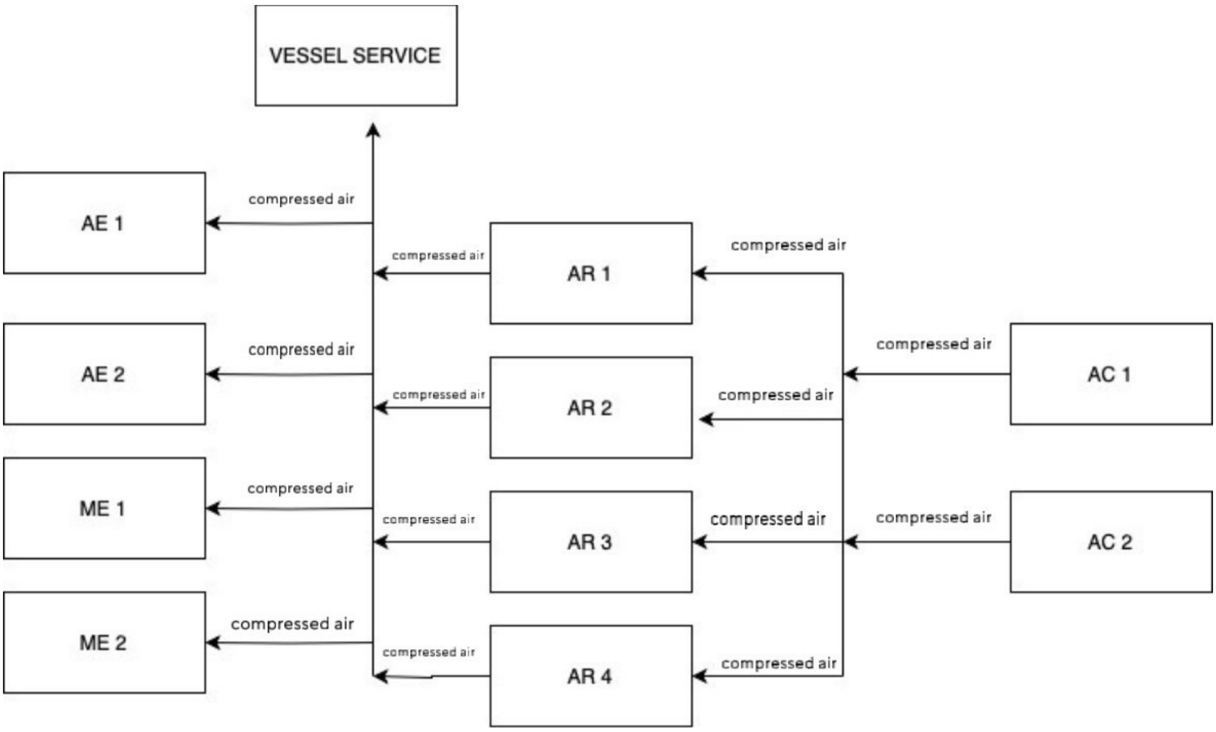
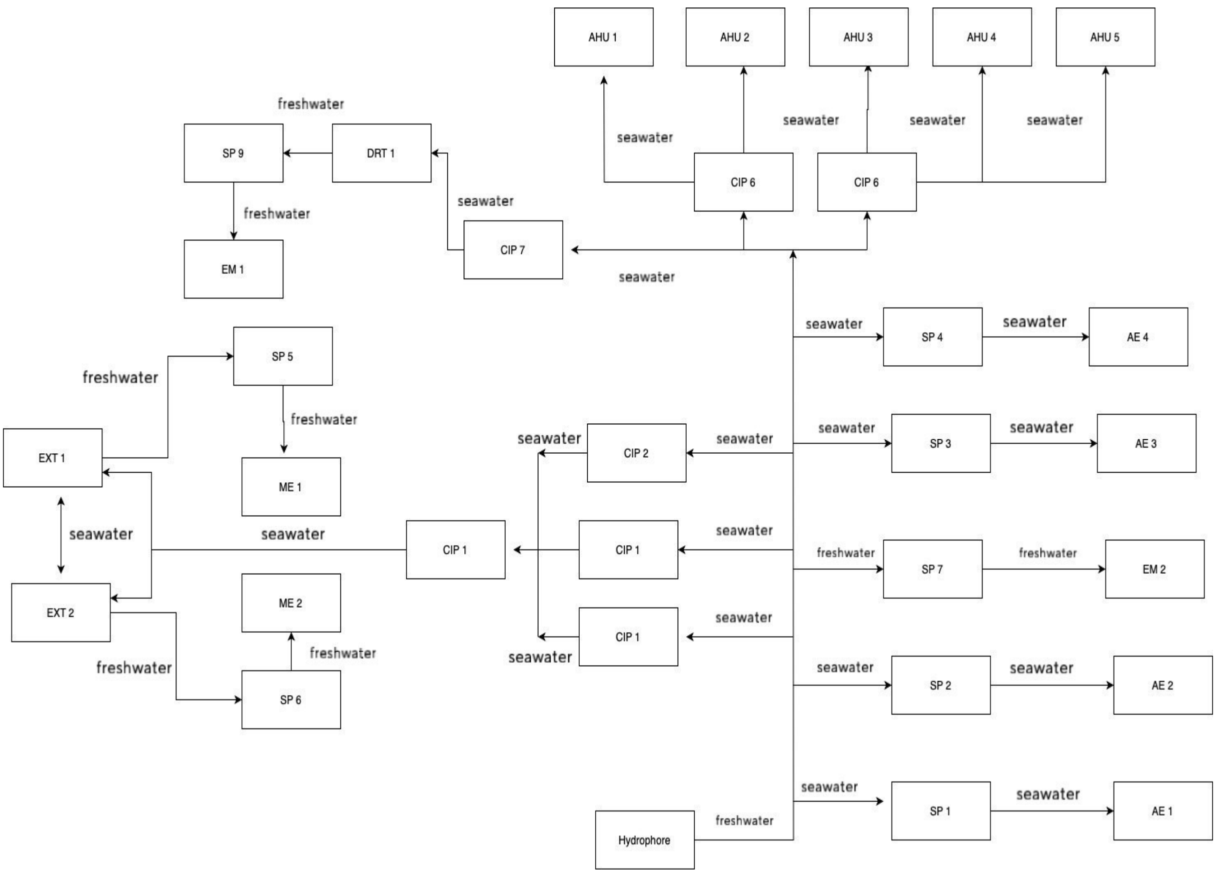
ATTACHMENT A

BLOCK DIAGRAM

Attachment Figure 1. Compressed Air System



Attachment Figure 2. Cooling System



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ATTACHMENT B

ANALYSIS FMECA, LOGIC TREE ANALYSIS, SUMMARY OF MAINTENANCE TASK ALOCATION PLANNING

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AS-01
System:	Diesel Engine	**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	remove moisture, oil, and other contaminants from the compressed air, ensuring that the air supplied to various onboard systems and equipment is clean, dry, and free from impurities.	Primary	1.1	stops removing moisture and contaminants, leading to unfiltered air entering the system (Total Failure)
			1.2	reduces its effectiveness, allowing more moisture or contaminants to pass through than normal. (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AS-01
System:	Diesel Engine	**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	.	External leak/rupture	**1.1 Condensation: Condensation occurs when warm, moisture-laden air comes into contact with cooler surfaces within the air separator system. This can happen in areas where temperature differentials exist, such as during**	Random	1. corrosion and degrade the integrity of system components. 2. condense on surfaces and contribute to the formation of water droplets	1.1stops removing moisture and contaminants, leading to unfiltered air entering the system (Total Failure) 1.2reduces its effectiveness, allowing more moisture or contaminants to pass through than normal. (Partial Failure)
			1.2 Air Leakage: Leakage of ambient air into the air separator system, particularly through damaged seals, gaskets, or faulty connections, can introduce moisture into the	Random		
		Corroded	**2.11. Component Wear: Wear and tear of internal components such as bearings, shafts, and gears can generate metal particles or debris that contaminate the lubricating oil. Abrasive wear between moving**	Wear-out	1. Reduced Seal Effectiveness 2. Internal Leakage	1.2reduces its effectiveness, allowing more moisture or contaminants to pass through than normal. (Partial Failure)
			2.2 Corrosion: Corrosion of metal components within the air separator system can lead to the formation of rust or metal oxides, which can contaminate the oil. Corrosion may occur due	Wear-out		
		Plugged/choked	**3.1 Accumulation of particulate matter or contaminants in the separation media: Over time, dust, debris, or other contaminants can accumulate in the air separator's separation media, such as coalescing filters or cyclonic**	Wear-out	1. Restricted airflow through the separation media, reducing the effectiveness of air separation and filtration. 2. Increased Friction	1.2reduces its effectiveness, allowing more moisture or contaminants to pass through than normal. (Partial Failure).
			3.2 Inadequate maintenance leading to clogged filtration media: Insufficient or irregular maintenance practices may result in the buildup of contaminants, obstructing	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AS-01
System:	Diesel Engine	**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	.	External leak/rupture	**The accumulation of moisture due to condensation can lead to several adverse consequences over time. These include increased corrosion of metal components within the air separator system, which can compromise their structural integrity and functionality. Additionally, the presence of moisture can create favorable conditions for microbial growth, leading to biofilm formation and potential contamination of the compressed air stream. Ultimately, unchecked condensation can result in reduced system efficiency, increased maintenance requirements, and potential operational failures.**	1	1	1	**Rendah**	1. Monitoring of moisture levels 2. visual inspection of drain valves	Implement a preventive maintenance schedule for regular inspection and cleaning of drain valves and associated components.
		Corroded	**Corrosion and Damage: Oil contamination containing abrasive particles or corrosive substances can accelerate corrosion and damage to internal components of the air separator system and other connected equipment. Corrosion can weaken structural integrity, promote fluid leaks, and compromise the safety and reliability of critical systems onboard the ship. Additionally, abrasive contaminants can cause accelerated wear and tear on components, leading to premature failure and the need for costly repairs or replacements.**	2	1	1	**Rendah**	1. Visual inspection of compressor components 2. Analysis of compressed air quality	Replacement of oil removal filters or coalescing elements according to manufacturer's recommendations.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
		Plugged/choked	**Degradation of Air Quality: Mechanical wear and tear may compromise the ability of the air separator to effectively remove contaminants and moisture from the compressed air stream. This can lead to degraded air quality, including increased levels of particulates, moisture content, and contaminants, which may adversely affect downstream processes and equipment..**	1	1	1	**Rendah**	1. Monitoring of pressure differentials 2. airflow patterns within the air separator.	Scheduled inspection and cleaning of separation media according to manufacturer recommendations or operational guidelines.

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AS-01
System:	Diesel Engine	**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	.	External leak/rupture	1	1	Rendah	Implement measures to regulate and maintain consistent temperatures within the air separator system to minimize temperature differentials.	1	Rendah	-
		Corroded	2	1	Rendah	Schedule and perform regular maintenance to check and replace worn components such as bearings, shafts, and gears.	1	Rendah	-
		Plugged/choked	1	1	Rendah	Develop and adhere to a regular maintenance schedule to ensure timely cleaning and replacement of filtration media.	1	Rendah	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	External leak/rupture	1.1 Condensation: Condensation occurs when warm, moisture-laden air comes into contact with cooler surfaces within the air separator system. This can happen in areas where temperature differentials exist, such as during system shutdowns or when ambient temperatures fluctuate. Condensation can lead to the buildup of moisture within the system over time.	no	STOP	STOP	no	NID	wo	STOP	STOP	no	NID	hid	yes	failure finding	STOP
		1.2 Air Leakage: Leakage of ambient air into the air separator system, particularly through damaged seals, gaskets, or faulty connections, can introduce moisture into the system. As air containing moisture infiltrates the system, it can contribute to the accumulation of water vapor and condensation, especially in regions with high humidity levels.	no	STOP	STOP	no	NID	wo	STOP	STOP	no	NID	hid	yes	failure finding	STOP
2	Corroded	2.11. Component Wear: Wear and tear of internal components such as bearings, shafts, and gears can generate metal particles or debris that contaminate the lubricating oil. Abrasive wear between moving parts can also lead to the release of fine particles that mix with the oil, causing contamination.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Corrosion: Corrosion of metal components within the air separator system can lead to the formation of rust or metal oxides, which can contaminate the oil. Corrosion may occur due to exposure to moisture or corrosive substances, such as acidic gases or chemicals present in the operating environment.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
3	Plugged/choked	3.1 Accumulation of particulate matter or contaminants in the separation media: Over time, dust, debris, or other contaminants can accumulate in the air separator's separation media, such as coalescing filters or cyclonic separators.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group		**Equipment ID:**	CA-AS-01
System:	Diesel Engine		**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System		**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Clean and inspect drain valves, seals, and connections to prevent clogging.	FF	1.1 1.2	Rendah	Rendah	500 hours of operation and/or Performed on: Accumulated debris or blockage is detected Routine maintenance check	-	Performed by an experienced technician

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group		**Equipment ID:**	CA-AS-01
System:	Diesel Engine		**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System		**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Replace oil removal filters or coalescing elements based on performance or schedule, and ensure proper installation.	PM	2.1 2.2	Rendah	Rendah	1000 hours of operation and/or Performed on: Reduction in performance is observed According to the proactive replacement schedule	-	Carried out by a trained mechanic

SUMMARY OF MAINTENANCE TASK

CATEGORY C

Functional Group:	Propulsion Function Group		**Equipment ID:**	CA-AS-01
System:	Diesel Engine		**Equipment Name:**	Air Separator
Subsystem:	Compressed Air System		**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Inspect, clean, and replace separation media as needed to maintain performance.	PM	3.1 3.2	Rendah	Rendah	2000 hours of operation and/or Performed on: Signs of reduced separation efficiency or performance Routine maintenance schedule as per manufacturer guidelines	-	Follow manufacturer instructions

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Compress atmospheric air to supply pressurized air for engine starting, tools, and systems, with a power output of 7.5 PS, capacity of 30 m³/hr, and operating at 550 RPM.	Primary	1.1	Failed to start air compressor, unable to operate (Total Failure)
			1.2	Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	Air filter	Contaminants carried over into compressed gas	**1.1 Accumulation of dust and debris : Contaminants such as dust, dirt, or debris present in the ambient air can enter the compressor system through the intake filters and other openings. These contaminants can**	Wear-out	1. Accumulation of contaminants 2. Gradual buildup of moisture	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			1.2 Moisture Accumulation : Moisture in the ambient air can condense within the compressor system due to temperature differentials or high humidity conditions. This	Wear-out		
		Operates at excessive temperature performance	**2.1Overheating: Excessive heat generated during motor operation can cause thermal expansion of the rotor material, leading to deformation over time. Overheating can occur due to prolonged operation at high loads,**	Wear-out	1. Increased Friction and Heat: 2. Vibration and Noise	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			2.2 Mechanical Stress: High mechanical loads or sudden impacts can cause the rotor to deform. This can happen if the compressed experiences sudden changes in flow rate,	Wear-out		
		Fails to start on demand	**3.1 Moisture and Humidity: Continuous exposure to moisture and high humidity levels in the compressed air area can create a corrosive environment that promotes the degradation of metal surfaces, including the**	Wear-out	1. Electrical Issues: 2. Vibration and Noise	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			3.2 Lack of Maintenance: Insufficient maintenance or neglecting to clean and dry the compressed air area regularly can allow corrosive substances to accumulate and	Wear-out		
	Intercooler	Fails to start on demand	**4.1 Electrical Wiring Fault: This cause involves issues with the wiring connected to the Intercooler , such as short circuits, loose connections, or damaged insulation.**	Random	1.Interruption or erratic behavior of electrical signals 2. Degradation of electrical components	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			4.2 Component Damage: Damage to electrical components within the Intercooler , such as solenoids or sensors, due to wear and tear or external factors.	Random		
			5.1 insulation Damage: Damage to the insulation of the stator windings can create			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
2	-	Operates at excessive temperature performance	**unintended electrical paths between the windings, resulting in a short circuit. Insulation damage may occur due to**	Random	1. Voltage Drop 2. Electrical Damage	1.1Failed to start air compressor, unable to operate (Total Failure)
			5.2 Overvoltage: Exposure to overvoltage conditions, such as voltage spikes or electrical surges, can exceed the breakdown voltage of the stator insulation, leading to	Random		
		Fails to start on demand	**6.1 Wire Breakage: Breakage or damage to the stator windings or connecting wires can result in an open circuit. This can occur due to mechanical stress, vibration, or physical damage to the motor.**	Random	1. Inoperable Motor 2. Loss of Power	1.1Failed to start air compressor, unable to operate (Total Failure) 1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			6.2 Loose Connections: Loose or corroded connections between the stator windings and other electrical components can create resistance and eventually lead to an open	Random		
3	Flywheel	Contaminants carried over into compressed gas	**7.1 Insufficient lubrication or lubricant contamination : Pressure Regulator fails to provide adequate lubrication to the Flywheel and Screw components of the air compressor.**	Wear-out	1. Increased friction between Screw and Flywheel wall due to lack of lubrication 2. Abrasion of Flywheel wall and Screw surfaces by foreign particles present in the lubricating oil	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			7.2 Foreign particle ingress or abrasive contaminants in the compression chamber : This cause involves the entry of foreign particles, such as dust, dirt, or debris, into the Flywheel and Screw area. These particles can	Wear-out		
		Operates at degraded head/flow performance	**8.1 Normal Wear and Tear: Over time, the constant rotation of the motor shaft places mechanical stress on the flywheel, leading to gradual wear. This wear is a natural consequence of the motor's operation and can**	Wear-out	1. Increased Friction 2.Abnormal Noise and Vibration	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			8.2 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the	Wear-out		
		Operates at excessive temperature performance	**9.1 Excessive wear or misalignment of Screw and Flywheel components : Wear can result from prolonged use, particularly under high operating pressures and speeds, causing the**	Wear-out	1. Abnormal Noise and Vibration 2. Reduced Efficiency	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			9.2 Imbalance: An imbalance in the rotating components of the motor, such as the rotor or impeller, can cause uneven forces on the flywheel, resulting in vibration.	Wear-out		
			10.1 Overheating due to inadequate cooling or lubrication : Inadequate cooling may result from issues such as insufficient airflow	Wear-out	1. Binding of Screw within the Flywheel	

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
4	Screw	Operates at degraded head/flow performance	**through the cooling system, malfunctioning**		within the Flywheel , halting compressor operation 2. Increased friction between Screw and Flywheel , leading to potential seizure	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			10.2 Excessive wear or misalignment of Screw and Flywheel components : Wear can result from prolonged use, particularly under high operating pressures and speeds, causing the surfaces of the Screw	Wear-out		
		Operates at excessive temperature performance	**11.1 Normal Wear and Tear: Over time, the constant rotation of the motor shaft places mechanical stress on the flywheel, leading to gradual wear. This wear is a natural consequence of the motor's operation and can**	Wear-out	1. Reduced Efficiency 2. Abnormal Noise and Vibration	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			11.2 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the	Wear-out		
		Fails to start on demand	**12.1 Imbalance: An imbalance in the rotating components of the motor, such as the rotor or impeller, can cause uneven forces on the flywheel, resulting in vibration.**	Wear-out	1. Reduced Efficiency: 2.decreased compressed	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			12.2 Loose Components: Loose components within the motor assembly, such as fasteners or mounting bolts, can cause vibration as the motor operates.	Random		
5	Rings	Operates at degraded head/flow performance	**13.1 Insufficient lubrication or poor lubricant quality : Without adequate lubrication, the surfaces of the Screw and Flywheel may experience increased friction during**	Wear-out	1.Increased friction 2. Abrasion and scoring	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			13.2 Contamination with abrasive particles or corrosive substances : When abrasive particles, such as dirt, dust, or metal fragments, enter the system, they can embed themselves between the Screw	Wear-out		
		Operates at excessive head/flow performance	**14.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing**	Wear-out	1. Abnormal Noise and Vibration 2.echanical stress	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			14.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or	Wear-out		
			15.1 Loose electrical connections due to vibrations or poor installation : These loose connections can occur at terminal points,	Random		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Fails to start on demand	**junctions, or wire connectors within the electrical circuitry of the compressor.**	Random	1. Fluctuations or loss of power supply 2.system experiences irregularities	1.1Failed to start air compressor, unable to operate (Total Failure)
			15.2 Short circuits : caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	Random		
6	Control Panel	Operates at excessive temperature performance	**16.1 C Wear or damage to rod flywheel : When rod flywheel wear or become damaged, they can lead to increased friction and heat generation between the Rings and Flywheel**	Wear-out	1.Misalignment between Screw and Flywheel 2. Increased Friction	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			16.2 Excessive mechanical stress or load on the Rings : When the Rings experiences excessive stress, it can lead to deformation, bending, or even fracture.	Wear-out		
		Operates at excessive head/flow performance	**17.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing**	Wear-out	1. Abnormal Noise and Vibration 2. echanical stress	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			17.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or	Wear-out		
		Fails to start on demand	**18.1 Loose electrical connections due to vibrations or poor installation : Vibrations can cause electrical terminals, connectors, or wiring to become loose over time, leading to intermittent electrical contact or complete**	Wear-out	1. Fluctuations or loss of power supply 2.voltage fluctuations	1.1Failed to start air compressor, unable to operate (Total Failure)
			18.2 Short circuits : caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	Wear-out		
	Pressure Regulator	Operates at degraded head/flow performance	**19.1 Fatigue failure due to cyclic loading : This type of failure often stems from the reciprocating motion of the Screw , which exerts alternating tensile and**	Wear-out	1.Formation of cracks 2. Increased Friction	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			19.2 Overheating due to friction or excessive mechanical stress : when the Pressure Regulator fails to adequately reduce friction between the Rings and other moving parts, such as the Screw or Flywheel.	Wear-out		
		Operates at excessive	**20.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient**	Wear-out		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
7		Operates at excessive temperature performanc	**lubrication reduces the effectiveness of the lubricant in reducing friction and preventing**		1. Abnormal Noise and Vibratio 2. mechanical stress	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			20.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or	Wear-out		
		Fails to start on demand	**21.1 Loose electrical connections due to vibrations or poor installation. Vibrations can cause nuts, bolts, terminals, or wiring connections to gradually loosen over time, compromising the electrical integrity of the**	Wear-out	1. Fluctuations 2. loss of power supply to the control panel.	1.2Loss of compressed air supply under 7,5 PS, capacity 30 m3/hrs (Partial Failure)
			21.2 Short circuits caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	Air filter	Contaminants carried over into compressed gas	**Reduced airflow decreases the compressor's capacity to generate compressed air, resulting in decreased system performance, increased energy consumption, and potential overheating or mechanical damage to the compressor.**	3	1	1	Rendah-Menengah	1. Check for low airflow indicators or alarms. 2. Measure the compressor's output pressure	Regular cleaning or replacement of air filter according to manufacturer guidelines to prevent blockage and ensure proper airflow.
		Operates at excessive temperature performance	**Reduced compressed efficiency: A deformed rotor disrupts fluid flow, decreasing the air compressor's effectiveness in removing water from the ship's compartments.**	2	1	2	Rendah	1. Monitor for reduced air pressure and efficiency. 2. Perform visual and mechanical inspections of the rotor for signs of deformation.	Regularly inspect compressed rotor for warping or bending.
		Fails to start on demand	**Diminished compressed efficiency: Corrosion on the rotor surface impedes fluid flow, reducing the compressed air compressed's ability to effectively remove water from ship compartments..**	2	1	1	Rendah	1. inspect the rotor surface for signs of corrosion or pitting. 2. Monitor compressor efficiency and performance metrics.	Inspect rotors for corrosion include rust formation or deterioriation
2	Intercooler	Fails to start on demand	**Potential damage to electrical components: Continued operation with a ground fault can lead to further damage or complete failure of electrical components.**	3	1	2	Rendah-Menengah	1. Check for electrical faults or alarms indicating ground faults. 2. Inspect electrical components for signs of damage or overheating.	Regular inspection and testing of electrical wiring and connections
		Operates at excessive temperature performance	**Complete compressed failure: A short circuit can render the air compressor inoperable, preventing it from removing water from the compressed air. This can lead to flooding, compromising stability and increasing the risk of capsizing.**	2	3	3	Rendah-Menengah	1. Observe for complete inoperability or failure to start. 2. Check for short circuit alarms or error codes.	Isolate the circuit to stop electricity flow and prevent further damage.
	-	Fails to start on demand	**Loss of compressed Functionality: An open circuit in the stator of a air compressor can cause the compressed to fail, resulting in the inability to remove water from the compressed air.**	2	1	1	Rendah	1. Detect the inability to operate or reduced performance. 2. Measure electrical continuity and inspect for open circuits.	isolate the affected circuit, inspect and repair wiring, replace damaged components,
			Accelerated wear on screw and Flywheel					1. Abnormal noise or vibration during	Implement a regular

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
3	Flywheel	Contaminants carried over into compressed gas	**surfaces, potential scoring or galling : o the phenomenon where these critical components experience faster-than-normal degradation, leading to surface irregularities and potential damage. This accelerated wear can occur due**	2	1	1	Rendah	1. Abnormal noise or vibration during compressor operation. 2. Inspection of compressed air for contaminants and particle filters.	Implement a regular maintenance program to inspect, clean, lubricate, and test the pressure relief valve .
		Operates at degraded head/flow performance	**Reduced compressed reliability: Worn flywheel lead to increased friction and vibration in the air compressor assembly, resulting in decreased compressed efficiency, erratic operation, and potential compressed failure, endangering operational**	2	2	2	Rendah-Menengah	1. Abnormal noise 2. corrosion visible damage	Implement a scheduled maintenance program
		Operates at excessive temperature performance	**Risk of Electrical Hazards: Vibrating motor casing can lead to loosening of electrical connections or damage to wiring, increasing the risk of electrical malfunctions or short circuits, posing safety hazards to crew members and equipment onboard the ship.**	2	1	1	Rendah	1. Abnormal noise and vibration	Conduct routine maintenance, cleaning, and lubrication of the drain valve
4	Screw	Operates at degraded head/flow performance	**Potential damage to screw rings, Flywheel wall, and other components : When these components are subjected to stress beyond their design limits, they may experience wear, scoring, or even deformation.**	2	3	1	Rendah-Menengah	1. Monitoring of compressor temperature and lubrication systems. 2. Visual inspection of screw-Flywheel interface for signs of wear.	Conduct routine maintenance, cleaning, and lubrication of the drain valve
		Operates at excessive temperature performance	**System Inefficiency: Persistent leakage compromises the efficiency of the system, resulting in increased energy consumption, decreased productivity, and potential damage to downstream components.**	2	1	1	Rendah	1. Abnormal noise 2. Reduce compressed efficiency	Replace worn or damaged seals with new ones made of compatible materials to restore proper sealing and prevent leakage.
		Fails to start on demand	**Water Supply Disruption: Complete blockage of the valve passage can disrupt water supply to critical areas, causing inconvenience, operational disruptions, and potential safety hazards.**	2	1	1	Rendah	1. Measure system performance and detect reduced efficiency.	Implement a routine maintenance schedule to flush or clean the valve to remove accumulated debris, sediment, or scale deposits.
5	Rings	Operates at degraded head/flow performance	**Potential damage to screw rings, Flywheel wall, and other components : When these components are subjected to stress beyond their design limits, they may experience wear, scoring, or even deformation.**	2	3	2	Rendah-Menengah	1. Detect interruptions in water supply and operational disruptions.	Conduct routine maintenance, cleaning, and lubrication of the drain valve
		Operates at excessive head/flow performance	**System Inefficiency: Persistent leakage compromises the efficiency of the system, resulting in increased energy consumption**	2	1	1	Rendah	1. Inspect for wear, damage, or	Seal Replacement: Replace worn or damaged seals with new

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
			resulting in increased energy consumption, decreased productivity, and potential damage to downstream components.	2	1	1	**Rendah**	deformation in Ringss and flywheel.	ones made of compatible materials to restore proper sealing and
		Fails to start on demand	**Water Supply Disruption: Complete blockage of the valve passage can disrupt water supply to critical areas, causing inconvenience, operational disruptions, and potential safety hazards.**	3	1	1	**Rendah-Menengah**	1. Observe for loose electrical connections and potential wiring damage.	Regular Cleaning: Implement a routine maintenance schedule to flush or clean the valve to remove accumulated debris, sediment, or
6	Control Panel	Operates at excessive temperature performance	**Potential damage to Rings and Pressure Regulator bearing : Excessive mechanical stress or load on the Rings, often caused by misalignment, improper lubrication, or overloading of the compressor, can lead to accelerated wear and fatigue failure of the**	2	3	1	**Rendah-Menengah**	1. Monitor for unusual vibrations or noises from the flywheel.	Conduct routine maintenance, cleaning, and lubrication of the drain valve to remove debris, sediment, or corrosion and ensure
		Operates at excessive head/flow performance	**Risk of Electrical Hazards: Vibrating motor casing can lead to loosening of electrical connections or damage to wiring, increasing the risk of electrical malfunctions or short circuits, posing safety hazards to crew members and equipment onboard the ship.**	2	1	1	**Rendah**	1. Monitor for increased friction, noise, or vibrations in the Rings area.	Scheduled inspection and non-destructive testing to detect early signs of crack formation, followed by repair or replacement as
		Fails to start on demand	**Risk of Electrical Hazards: Vibrating motor casing can lead to loosening of electrical connections or damage to wiring, increasing the risk of electrical malfunctions or short circuits, posing safety hazards to crew members and equipment onboard the ship.**	2	2	2	**Rendah-Menengah**	1. Inspect for loose or damaged electrical connections and wiring.	Implement a routine maintenance schedule to flush or clean the valve to remove accumulated debris, sediment, or scale deposits.
7	Pressure Regulator	Operates at degraded head/flow performance	**Potential catastrophic failure of flywheel during operation.**	2	2	2	**Rendah-Menengah**	1. Observe for unusual vibrations or noises coming from the flywheel.	shut down the compressed and replace them with high-quality marine flywheel.
		Operates at excessive temperature performanc	**Reduced compressed reliability: Worn flywheel lead to increased friction and vibration in the air compressor assembly, resulting in decreased compressed efficiency, erratic operation, and potential compressed failure, endangering operational**	3	1	1	**Rendah-Menengah**	1. Inspect electrical connections and wiring for looseness or damage.	Replace worn or damaged seals with new ones made of compatible materials to restore proper sealing and prevent leakage.
		Fails to start on demand	**Risk of Electrical Hazards: Vibrating motor casing can lead to loosening of electrical connections or damage to wiring, increasing the risk of electrical malfunctions or short circuits, posing safety hazards to crew**	2	1	1	**Rendah**	1. Inspect flywheel for signs of wear, damage, or deformation..	Shut down the compressed and inspect for misalignment, imbalance, or worn components

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	Air filter	Contaminants carried over into compressed gas	3	1	Rendah-Menengah	Replace intake filters periodically to prevent dust and debris from entering the system.	1	Rendah-Menengah	-
		Operates at excessive temperature performance	2	1	Rendah	Install moisture separators to reduce the amount of moisture entering the system.	1	Rendah	-
		Fails to start on demand	2	1	Rendah	Enhance the cooling system by adding ventilation or repairing cooling fans.	1	Rendah	-
2	Intercooler	Fails to start on demand	3	1	Rendah-Menengah	Monitor and adjust flow rates to avoid sudden changes that can cause mechanical stress.	1	Rendah-Menengah	-
		Operates at excessive temperature performance	2	3	Rendah-Menengah	Implement humidity control systems to maintain safe moisture levels	2	Rendah-Menengah	-

						levels.			
	-	Fails to start on demand	2	1	**Rendah**	Set up a regular maintenance schedule to ensure components are clean and functioning properly.	1	**Rendah**	-
	Flywheel	Contaminants carried over into compressed gas	2	1	**Rendah**	Check and repair all electrical connections to prevent short circuits or other issues.	1	**Rendah**	-
3		Operates at degraded head/flow performance	2	2	**Rendah-Menengah**	Replace damaged components such as solenoids or sensors.	1	**Rendah**	-
		Operates at excessive temperature performance	2	1	**Rendah**	Regularly check insulation and repair or replace as needed.	1	**Rendah**	-
	Screw	Operates at degraded head/flow performance	2	3	**Rendah-Menengah**	Check for broken or damaged wires and replace them as necessary.	2	**Rendah-Menengah**	-
4		Operates at excessive temperature performance	2	1	**Rendah**	Ensure all connections are tight and secure, and check for corrosion.	1	**Rendah**	-

		Fails to start on demand	2	1	Rendah	Verify that the lubrication system is functioning correctly and that the right lubricant is used.	1	Rendah	-
5	Rings	Operates at degraded head/flow performance	2	3	Rendah-Menengah	Use appropriate air filters to prevent foreign particles from entering the system.	2	Rendah-Menengah	-
		Operates at excessive head/flow performance	2	1	Rendah	Regularly monitor the wear levels and replace components as needed.	1	Rendah	-
		Fails to start on demand	3	1	Rendah-Menengah	Ensure rotating components are balanced to reduce vibrations.	1	Rendah-Menengah	-
6	Control Panel	Operates at excessive temperature performance	2	3	Rendah-Menengah	Enhance the efficiency of the cooling system to ensure adequate cooling.	2	Rendah-Menengah	-
		Operates at excessive head/flow performance	2	1	Rendah	Confirm that lubrication is performed properly and on schedule.	1	Rendah	-

		Fails to start on demand	2	2	**Rendah-Menengah**	Check and tighten all electrical connections.	1	**Rendah**	-
7	Regulator	Operates at degraded head/flow performance	2	2	**Rendah-Menengah**	Track and manage cyclic loads to reduce the risk of fatigue failure.	1	**Rendah**	-
		Operates at excessive temperature performanc	3	1	**Rendah-Menengah**	Ensure the lubrication system is effective to reduce friction.	1	**Rendah-Menengah**	-
		Fails to start on demand	2	1	**Rendah**	Regularly inspect and secure all electrical connections.	1	**Rendah**	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Contaminants carried over into compressed gas	1.1 Accumulation of dust and debris : Contaminants such as dust, dirt, or debris present in the ambient air can enter the compressor system through the intake filters and other openings. These contaminants can accumulate over time within the compressor components, obstructing airflow passages and causing clogging.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	NO	NID	STOP	STOP	STOP	STOP
		1.2 Moisture Accumulation : Moisture in the ambient air can condense within the compressor system due to temperature differentials or high humidity conditions. This moisture can accumulate within the compressor components over time, leading to corrosion, rust formation, and blockage.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	NO	NID	STOP	STOP	STOP	STOP
2	Operates at excessive temperature performance	2.1Overheating: Excessive heat generated during motor operation can cause thermal expansion of the rotor material, leading to deformation over time. Overheating can occur due to prolonged operation at high loads, inadequate cooling, or electrical faults.	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Mechanical Stress: High mechanical loads or sudden impacts can cause the rotor to deform. This can happen if the compressed experiences sudden changes in flow rate, pressure, or if it encounters debris or obstructions in the compressed air water.	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
3	Fails to start on demand	3.1 Moisture and Humidity: Continuous exposure to moisture and high humidity levels in the compressed air area can create a corrosive environment that promotes the degradation of metal surfaces, including the rotor.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		3.2 Lack of Maintenance: Insufficient maintenance or neglecting to clean and dry the compressed air area regularly can allow corrosive substances to accumulate and cause corrosion of the rotor over time.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

4	Fails to start on demand	4.1 Electrical Wiring Fault: This cause involves issues with the wiring connected to the Intercooler , such as short circuits, loose connections, or damaged insulation. mechanical shock.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		4.2 Component Damage: Damage to electrical components within the Intercooler , such as solenoids or sensors, due to wear and tear or external factors.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
5	Operates at excessive temperature performance	5.1 insulation Damage: Damage to the insulation of the stator windings can create unintended electrical paths between the windings, resulting in a short circuit. Insulation damage may occur due to mechanical stress, overheating, moisture ingress, or aging of the insulation materials.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		5.2 Overvoltage: Exposure to overvoltage conditions, such as voltage spikes or electrical surges, can exceed the breakdown voltage of the stator insulation, leading to insulation breakdown and short circuits.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
6	Fails to start on demand	6.1 Wire Breakage: Breakage or damage to the stator windings or connecting wires can result in an open circuit. This can occur due to mechanical stress, vibration, or physical damage to the motor.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		6.2 Loose Connections: Loose or corroded connections between the stator windings and other electrical components can create resistance and eventually lead to an open circuit. This can occur due to poor installation practices or improper maintenance.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
	Contaminants carried over into compressed	7.1 Insufficient lubrication or lubricant contamination : Pressure Regulator fails to provide adequate lubrication to the Flywheel and Screw components of the air compressor. It could result from issues such as low oil levels, degraded lubricant quality, or malfunctioning lubrication pumps.	no	STOP	STOP	no	NID	wo	no	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

7	over into compressed gas	7.2 Foreign particle ingress or abrasive contaminants in the compression chamber : This cause involves the entry of foreign particles, such as dust, dirt, or debris, into the Flywheel and Screw area. These particles can come from various sources, including the environment, improper maintenance practices, or degradation of internal components like seals or gaskets.	no	STOP	STOP	no	NID	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
8	Operates at degraded head/flow performance	8.1 Normal Wear and Tear: Over time, the constant rotation of the motor shaft places mechanical stress on the flywheel, leading to gradual wear. This wear is a natural consequence of the motor's operation and can occur even under normal operating conditions.	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		8.2 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing metal-to-metal contact between bearing components.	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
9	Operates at excessive temperature performance	9.1 Excessive wear or misalignment of Screw and Flywheel components : Wear can result from prolonged use, particularly under high operating pressures and speeds, causing the surfaces of the Screw and Flywheel to gradually degrade. Misalignment may occur due to improper assembly, maintenance issues, or mechanical stresses during operation.	no	STOP	STOP	no	NID	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		9.2 Imbalance: An imbalance in the rotating components of the motor, such as the rotor or impeller, can cause uneven forces on the flywheel, resulting in vibration.	no	STOP	STOP	no	NID	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

10	Operates at degraded head/flow performance	10.1 Overheating due to inadequate cooling or lubrication : Inadequate cooling may result from issues such as insufficient airflow through the cooling system, malfunctioning cooling fans, or blockages in the cooling channels. Without proper cooling, the compressor's internal components, including the Flywheel and Screw , can heat up excessively during operation	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		10.2 Excessive wear or misalignment of Screw and Flywheel components : Wear can result from prolonged use, particularly under high operating pressures and speeds, causing the surfaces of the Screw and Flywheel to gradually degrade. Misalignment may occur due to improper assembly, maintenance issues, or mechanical stresses during operation.	no	STOP	STOP	no	**NID**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
11	Operates at excessive temperature performance	11.1 Normal Wear and Tear: Over time, the constant rotation of the motor shaft places mechanical stress on the flywheel, leading to gradual wear. This wear is a natural consequence of the motor's operation and can occur even under normal operating conditions.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		11.2 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing metal-to-metal contact between bearing components.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
12	Fails to start on demand	12.1 Imbalance: An imbalance in the rotating components of the motor, such as the rotor or impeller, can cause uneven forces on the flywheel, resulting in vibration.	no	STOP	STOP	no	**NID**	wo	no	STOP	NO	NID	EVD	NO	evident	One-time change
		12.2 Loose Components: Loose components within the motor assembly, such as fasteners or mounting bolts, can cause vibration as the motor operates.	no	STOP	STOP	no	**NID**	wo	no	STOP	no	NID	EVD	NO	evident	One-time change

13	Operates at degraded head/flow performance	13.1 Insufficient lubrication or poor lubricant quality : Without adequate lubrication, the surfaces of the Screw and Flywheel may experience increased friction during operation. This heightened friction can result in accelerated wear and tear on the components, leading to surface damage, scoring, or galling.	no	STOP	STOP	no	NID	wo	no	STOP	no	NID	EVD	NO	evident	One-time change
		13.2 Contamination with abrasive particles or corrosive substances : When abrasive particles, such as dirt, dust, or metal fragments, enter the system, they can embed themselves between the Screw and Flywheel surfaces during operation.	no	STOP	STOP	no	NID	wo	no	STOP	no	NID	EVD	NO	evident	One-time change
14	Operates at excessive head/flow performance	14.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing metal-to-metal contact between bearing components.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		14.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or blockages, causing the motor to work harder than intended.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
15	Fails to start on demand	15.1 Loose electrical connections due to vibrations or poor installation : These loose connections can occur at terminal points, junctions, or wire connectors within the electrical circuitry of the compressor.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		15.2 Short circuits : caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
16	Operates at excessive temperature performance	16.1 C Wear or damage to rod flywheel : When rod flywheel wear or become damaged, they can lead to increased friction and heat generation between the Rings and Flywheel journal.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		16.2 Excessive mechanical stress or load on the Rings : When the Rings experiences excessive stress, it can lead to deformation, bending, or even fracture.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

17	Operates at excessive head/flow performance	17.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing metal-to-metal contact between bearing components.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		17.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or blockages, causing the motor to work harder than intended.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
18	Fails to start on demand	18.1 Loose electrical connections due to vibrations or poor installation : Vibrations can cause electrical terminals, connectors, or wiring to become loose over time, leading to intermittent electrical contact or complete disconnection.	no	STOP	STOP	NO	NID	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		18.2 Short circuits : caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	no	STOP	STOP	NO	NID	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
19	Operates at degraded head/flow performance	19.1 Fatigue failure due to cyclic loading : This type of failure often stems from the reciprocating motion of the Screw , which exerts alternating tensile and compressive forces on the Rings during each stroke of the compressor.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		19.2 Overheating due to friction or excessive mechanical stress : when the Pressure Regulator fails to adequately reduce friction between the Rings and other moving parts, such as the Screw or Flywheel.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
20	Operates at excessive temperature performanc	20.1 Lubrication Issues: Inadequate lubrication or contamination of the lubricant can accelerate bearing wear. Insufficient lubrication reduces the effectiveness of the lubricant in reducing friction and preventing metal-to-metal contact between bearing components.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	NO	NID	STOP	STOP	STOP	STOP

		20.2 Overloading: Excessive load on the motor can accelerate bearing wear. Overloading occurs when the air compressor encounters unusually high water levels or blockages, causing the motor to work harder than intended.	no	STOP	STOP	yes	**Condition Monitoring**	wo	no	STOP	NO	NID	STOP	STOP	STOP	STOP
21	Fails to start on demand	21.1 Loose electrical connections due to vibrations or poor installation. Vibrations can cause nuts, bolts, terminals, or wiring connections to gradually loosen over time, compromising the electrical integrity of the system.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		21.2 Short circuits caused by water ingress or insulation breakdown and Component failure due to aging or manufacturing defects.	no	STOP	STOP	yes	Condition Monitoring	wo	no	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
clean or replace the air filter according to manufacturer guidelines	CM	1.1 1.2	Rendah-Menengah	Rendah-Menengah	500 hours and/or Performed on: After significant dust accumulation During routine maintenance checks	-	Performed by a technician
Perform inspections and testing of electrical wiring and components, replace damaged parts, and protect from moisture and extreme conditions.	CM/PM	4.1 4.2	Rendah-Menengah	Rendah-Menengah	500 hours and/or Performed on: After electrical faults or issues During scheduled electrical system checks	-	Conducted by a skilled technician
Isolate the circuit, inspect and repair wiring, replace damaged components, and conduct routine maintenance to prevent short circuits.	CM/PM	5.1 5.2	Rendah-Menengah	Rendah-Menengah	1000 hours and/or Performed on: When short circuits or electrical faults are detected During regular electrical maintenance	-	Conducted by a skilled technician
Isolate the affected circuit, inspect and repair wiring, replace faulty components, and implement maintenance to ensure system reliability.	CM/PM	6.1 6.2	Rendah	Rendah	1000 hours and/or Performed on: When electrical issues are identified During routine system inspections	-	Immediate attention required

Follow a routine maintenance schedule to clean, lubricate, and test the pressure relief valve to ensure proper operation and compliance.	PM	7.1 7.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: As per manufacturer's guidelines During scheduled maintenance	-	Routine maintenance performed
clean and lubricate the drain valve to remove debris and ensure smooth operation.	PM	8.1 8.2	**Rendah-Menengah**	**Rendah**	500 hours and/or Performed on: When blockage or reduced performance is observed During routine maintenance checks	-	Action taken by maintenance staff
Clean the valve , check for smooth operation, and address any blockages promptly.	PM	10.1 10.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours and/or Performed on: When blockages are observed During routine maintenance	-	Scheduled maintenance completed
Inspect and repair any leaks in the system promptly to prevent efficiency losses and damage to downstream components.	CM/PM	17.1 17.2	**Rendah**	**Rendah**	As needed and/or Performed on: When leaks are detected During routine system checks	-	Immediate repair required
inspect and clean valve passages to ensure unobstructed water supply and prevent operational disruptions.	PM	18.1 18.2	**Rendah-Menengah**	**Rendah**	1000 hours and/or Performed on: When blockages are detected During regular maintenance	-	Maintenance performed
Secure electrical connections and components to prevent loosening and damage caused by vibrations, ensuring safety and operational reliability.	CM/PM	19.1 19.2	**Rendah-Menengah**	**Rendah**	500 hours and/or Performed on: When vibrations are detected During scheduled maintenance	-	Secured by maintenance team

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AC-01
System:	Diesel Engine	**Equipment Name:**	Air Compressor
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air
Sub-Subsystem:	Starting Main Engine		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Replace worn seals with compatible materials and maintain the valve to ensure proper sealing and functionality.	PM	9.1 9.2	Rendah-Menengah	Rendah-Menengah	1000 hours and/or Performed on: When seal degradation is detected During scheduled maintenance	-	Handled by a certified technician.
Conduct inspections and non-destructive testing for cracks, and repair or replace as necessary.	CM/PM	11.1 11.2	Rendah	Rendah	2000 hours and/or Performed on: When cracks or signs of fatigue are observed During scheduled inspections	-	Follow industry standards for non-destructive testing to accurately identify and address cracks.
Shutdown and replace flywheel with high-quality marine flywheel, and perform routine lubrication and inspections.	OTC	12.1 12.2	Rendah-Menengah	Rendah	1000 hours and/or Performed on: When bearing wear is detected During routine maintenance	-	erformed by a professional with experience in flywheel replacements.
Shutdown the compressor, check for misalignment and imbalance, correct issues, and implement vibration monitoring and damping measures.	OTC	13.1 13.2	Rendah	Rendah	1000 hours and/or Performed on: When vibration issues are observed During regular alignment checks	-	Executed by a trained technician.
Inspect Rings and Pressure Regulator flywheel for excessive wear or damage; replace as needed and ensure proper lubrication and alignment.	CM/PM	14.1 14.2	Rendah-Menengah	Rendah-Menengah	1000 hours and/or Performed on: When wear is detected During scheduled maintenance	-	Inspection and replacement should be done by a certified technician.

alignment.							
Inspect and address any issues affecting compressor efficiency, such as worn components or incorrect settings, to restore optimal performance.	CM	20.1 20.2	**Rendah**	**Rendah**	000 hours and/or Performed on: When efficiency issues are observed During routine maintenance	-	Follow the manufacturer's recommendations for inspecting and correcting issues affecting efficiency.
maintenance and inspections to address inefficiencies and ensure the reliable operation of the system	CM/PM	21.1 21.2	**Rendah-Menengah**	**Rendah**	1000 hours and/or Performed on: When inefficiencies are detected During scheduled system checks	-	Regular maintenance and inspections are crucial to ensure the reliable operation and longevity of the system.

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AR-01
System:	Diesel Engine	**Equipment Name:**	Air Receiver
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air System
Sub-Subsystem:	Starting Main Engine		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	storing compressed air to provide a steady and consistent supply of pressurized air to various pneumatic devices and equipment onboard the ship. Working Pressure on 2,94 Mpa and Capacity onr 200 Liter	Primary	1.1	Fails to store and distribute compressed air (Total Failure)
			1.2	Working Pressure under 2,94 Mpa (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AR-01
System:	Diesel Engine	**Equipment Name:**	Air Receiver
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air System
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic (5)	Local Effect (6)	Functional Failure (7)
1	Inlet and Outlet	Leakage	**1.1 Electrical Wiring Fault: This cause involves issues with the wiring connected to the inlet valve, such as short circuits, loose connections, or damaged insulation.**	Random	1. Interruption or erratic behavior of electrical signals 2. Degradation of electrical components	1.1 fails to store and distribute compressed air effectively 1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			1.2 Component Damage: Damage to electrical components within the inlet valve, such as solenoids or sensors, due to wear and tear or external factors.	Wear-out		
		Wear and Tear	**2.1 Continuous usage and friction between moving parts can lead to mechanical wear and tear of the inlet and outlet components, such as seals, gaskets, or valve seats, compromising their sealing effectiveness and**	Wear-out	1. Leakage Pathways 2. Reduced Sealing Effectiveness	1.1 fails to store and distribute compressed air effectively 1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			2.2 Over time, repeated opening and closing of the inlet and outlet valves, coupled with fluid flow and pressure fluctuations, result in abrasion, erosion, or deformation of the	Wear-out		
		Corroded	**3.1 Chemical Exposure: Exposure to corrosive chemicals or substances in the fluid being transported can lead to corrosion of the inlet and outlet components.**	Wear-out	1. Surface Degradation 2.Leakage Pathways	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			3.2 Abrasive Particles: Presence of abrasive particles or sediments in the fluid flow can cause erosion of the inlet and outlet surfaces over time.	Wear-out		
	Pressure	Inaccurate Reading	**4.1 Internal Damage: Internal components of the pressure gauge, such as the bourdon tube or dial mechanism, may become damaged due to wear and tear, excessive pressure, or**	Wear-out	1.Calibration drift 2.Sticking or Jamming	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			4.2 Calibration Drift: Over time, the accuracy of the pressure gauge may drift due to factors like environmental conditions, vibration, or exposure to corrosive substances, leading to incorrect pressure readings.	Wear-out		
			5.1 Physical Impact: Accidental impact or			1.1 Motor failed to start compressed

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic (5)	Local Effect (6)	Functional Failure (7)
2	Gauge -	Mechanical Damage	**mechanical shock to the pressure gauge, such as dropping heavy objects on it or bumping into it during maintenance activities, can cause mechanical damage.**	Random	1. Visible Damage 2. Functional Impairment	air compressed,unable to operate (Total Failure) 1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			5.2 Excessive Pressure: Exposure to pressures beyond the gauge's specified range or sudden pressure spikes in the system can overload the internal components, leading to	Random		
		Calibration Drift	**6.1 Environmental Factors: Changes in temperature, humidity, or atmospheric pressure can affect the properties of the pressure gauge's internal components, leading to calibration drift over time.**	Wear-out	1. Shift in Reading: 2. Erroneous Readings	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			6.2 Wear and Tear: Normal wear and tear on the gauge's mechanical or electronic components, such as the bourdon tube or sensing element, can cause gradual changes	Wear-out		
3	Pressure Relief	Plugged/choked inlet	**7.1 Spring Fatigue: Over time, the spring in the pressure relief valve may weaken or lose elasticity due to cyclic loading, high temperatures, or corrosion, resulting in**	Wear-out	1. Inadequate Pressure Relief 2. Leakage or Weepin	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			7.2 Buildup of Deposits: Accumulation of debris, scale, or sediment within the pressure relief valve can obstruct its mechanism, preventing proper operation and release of excess pressure.	Wear-out		
		Plugged/choked outlet	**8.1 Mechanical Obstruction: Accumulation of debris, corrosion, or foreign objects in the valve's internal passages or seat may prevent it from fully opening during overpressure conditions.**	Wear-out	1. Inadequate Pressure Relief 2. Increased Pressure Buildup	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			8.2 Spring Failure: Weakening or failure of the valve's spring mechanism, which provides the force necessary to open the valve, can lead to insufficient force to overcome the pressure.	Wear-out		
		External leak/rupture	**9.1 Seal Degradation: Deterioration or damage to the valve seals due to age, chemical exposure, or mechanical wear can result in leakage.**	Wear-out	1. Fluid Loss 2. Environmental Contamination	1.1 Motor failed to start compressed air compressed,unable to operate (Total Failure) 1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			9.2 Seat Misalignment: Misalignment of the valve seat or disc caused by improper installation, mechanical stress, or system vibration may lead to inadequate sealing and	Wear-out		
			10.1 Corrosion and Rust: Exposure to moisture			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic (5)	Local Effect (6)	Functional Failure (7)
4	Drain Valve	Plugged/choked inlet	**and corrosive elements can cause the drain valve components, such as seals, threads, or metal parts, to corrode or rust over time,**	Wear-out	1. Leakage or Dripping 2. Reduced Drainage Capacity	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			10.2 Sediment Buildup: Accumulation of debris, scale, or sediment within the drain valve can obstruct its operation, preventing proper opening or closure and resulting in blockages or leaks.	Wear-out		
		External leak/rupture.	**11.1 Seal Degradation: Deterioration or damage to the valve seals due to age, chemical exposure, or mechanical wear can result in leakage.**	Wear-out	1. Fluid Loss 2. Environmental Contamination	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			11.2 Corrosion: Corrosive substances present in the fluid or environment can corrode the valve components, compromising their integrity and causing leakage.	Wear-out		
		Plugged/choked outlet	**12.1 Debris Accumulation: Accumulation of dirt, sediment, or foreign objects in the valve passage can obstruct the flow path and prevent proper valve operation.**	Wear-out	1.. Reduced Flow Rate: 2. Increased Pressure Drop	1.2 Working Pressure under 2,94 Mpa 1.3 Capacity under 200 Liter
			12.2 Scaling: Scaling due to mineral deposits or corrosion products can form inside the valve, narrowing the passage and impeding fluid flow.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

DIGITAL MARINE OPERATION & MAINTENANCE

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AR-01
System:	Diesel Engine	**Equipment Name:**	Air Receiver
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air System
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	Inlet and Outlet	Leakage	**Potential damage to electrical components: Continued operation with a ground fault can lead to further damage or complete failure of electrical components.**	1	1	1	Rendah	1. Visual inspection 2. Monitoring of electrical signals	Regular inspection and testing of electrical wiring and connections
		Wear and Tear	**Fluid Loss: Inadequate sealing due to mechanical wear and tear results in fluid loss through the inlet and outlet valves, leading to wastage, reduced system efficiency, and potential contamination of surrounding areas.**	2	1	1	Rendah	1. Visual inspection 2. corrective action	implement a proactive maintenance program
		Corroded	**Fluid Contamination: Corroded or eroded inlet and outlet surfaces introduce contaminants into the fluid flow, potentially contaminating the sanitary supply system and downstream processes..**	2	1	1	Rendah	1. Visual inspection 2. Material Thickness Measuremen	Implement corrosion-resistant coatings, linings, or materials
2	Pressure Gauge	Inaccurate Reading	**System Mismanagement: Inaccurate pressure readings from the gauge can lead to improper system operation, such as overpressurization or underpressurization, which may cause equipment damage or system failure.**	1	1	2	Rendah	1.Functionality Test 2. Comparison with Reference Gauges	Implement a schedule for regular calibration
		Mechanical Damage	**Safety Hazard: Malfunctioning pressure gauges may fail to alert operators to unsafe pressure conditions, posing a safety hazard to personnel or equipment.**	1	1	1	Rendah	1. mechanical operation 2. Functionality Test	Install protective guards or shields around the pressure gauge
	-	Calibration Drift	**System Inefficiency: Inaccurate pressure readings due to calibration drift can lead to suboptimal system operation, affecting process efficiency, energy consumption, or product quality.**	1	1	1	Rendah	1. Calibration Checks 2. Functional Testing	Implement a regular calibration schedule
			Spring Fatigue: Over time, the spring in the						

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
3	Pressure Relief	Plugged/choked inlet	**Spring Fatigue: Over time, the spring in the pressure relief valve may weaken or lose elasticity due to cyclic loading, high temperatures, or corrosion, resulting in inadequate relief pressure.**	2	1	2	**Rendah**	1. Visual inspection 2. Pressure Monitoring	Implement a regular maintenance program
		Plugged/choked outlet	**System Overpressure: Failure of the pressure relief valve to open results in sustained overpressure conditions within the system, leading to potential equipment failure, leaks, or ruptures.**	2	1	1	**Rendah**	1. Visual inspection 2. Functional Testing	Implement a scheduled maintenance program
		External leak/rupture	**System Inefficiency: Persistent leakage compromises the efficiency of the system, resulting in increased energy consumption, decreased productivity, and potential damage to downstream components.**	2	1	2	**Rendah**	1. Visual inspection 2. Fluid Level Monitoring	Conduct routine maintenance, cleaning, and lubrication
4	Drain Valve	Plugged/choked inlet	**System Contamination: Inadequate drainage due to valve malfunction can result in the buildup of stagnant water or fluids within the system, promoting microbial growth, fouling, or contamination, compromising water quality and system integrity.**	2	1	1	**Rendah**	1. Visual inspection 2. Pressure Monitoring	Conduct routine maintenance, cleaning, and lubrication
		External leak/rupture.	**System Inefficiency: Persistent leakage compromises the efficiency of the system, resulting in increased energy consumption, decreased productivity, and potential damage to downstream components.**	2	1	1	**Rendah**	1. Visual inspection 2. Functional Testing	Replace worn or damaged seals with new ones made
		Plugged/choked outlet	**Water Supply Disruption: Complete blockage of the valve passage can disrupt water supply to critical areas, causing inconvenience, operational disruptions, and potential safety hazards.**	2	1	1	**Rendah**	1. Visual inspection 2. Fluid Level Monitoring	Conduct regular operational checks

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	0
System:	Diesel Engine	**Equipment Name:**	0
Subsystem:	Compressed Air System	**Drawing:**	0
Sub-Subsystem:	Starting Main Engine		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	Inlet and Outlet	Leakage	1	1	Rendah	Conduct routine inspections and repairs of electrical wiring to ensure there are no short circuits or loose connections.	1	Rendah	-
		Wear and Tear	2	1	Rendah	Perform regular maintenance to check and replace worn seals, gaskets, and valve seats.	1	Rendah	-
		Corroded	2	1	Rendah	Apply protective coatings to prevent corrosion on inlet and outlet components.	1	Rendah	-
2	Pressure Gauge	Inaccurate Reading	1	1	Rendah	Inspect and replace damaged internal components of the pressure gauge.	1	Rendah	-
		Mechanical Damage	1	1	Rendah	Provide physical protection for the pressure gauge to avoid mechanical impact or shock	1	Rendah	-

	-					mechanical impact or shock.			
		Calibration Drift	1	1	**Rendah**	Use environmental protection measures to maintain stable temperature, humidity, and atmospheric pressure conditions.	1	**Rendah**	-
3	Pressure Relief	Plugged/choked inlet	2	1	**Rendah**	Periodically replace the spring in the pressure relief valve to prevent spring fatigue.	1	**Rendah**	-
		Plugged/choked outlet	2	1	**Rendah**	Routinely clean the internal passages of the valve to prevent accumulation of debris or corrosion.	1	**Rendah**	-
		External leak/rupture	2	1	**Rendah**	Replace degraded or damaged valve seals to prevent leakage.	1	**Rendah**	-
4	Drain Valve	Plugged/choked inlet	2	1	**Rendah**	Apply anti-corrosion coatings to protect valve components from rust.	1	**Rendah**	-
		External leak/rupture.	2	1	**Rendah**	Regularly replace worn or damaged valve seals.	1	**Rendah**	-

		Plugged/choked outlet	2	1	**Rendah**	Regularly clean to remove dirt, sediment, or foreign objects in the valve passage.	1	**Rendah**	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Leakage	1.1 Electrical Wiring Fault: This cause involves issues with the wiring connected to the inlet valve, such as short circuits, loose connections, or damaged insulation.	no	STOP	STOP	yes	Condition Monitoring	WO	STOP	STOP	no	NID	yes	STOP	STOP	STOP
		1.2 Component Damage: Damage to electrical components within the inlet valve, such as solenoids or sensors, due to wear and tear or external factors.	no	STOP	STOP	yes	Condition Monitoring	WO	STOP	STOP	STOP	STOP	STOP	STOP	STOP	STOP
2	Wear and Tear	2.1 Continuous usage and friction between moving parts can lead to mechanical wear and tear of the inlet and outlet components, such as seals, gaskets, or valve seats, compromising their sealing effectiveness and integrity.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Over time, repeated opening and closing of the inlet and outlet valves, coupled with fluid flow and pressure fluctuations, result in abrasion, erosion, or deformation of the sealing surfaces, reducing their ability to form a tight seal and regulate fluid flow.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	YES	Plan Maintenance	yes	STOP	STOP	STOP
3	Corroded	3.1 Chemical Exposure: Exposure to corrosive chemicals or substances in the fluid being transported can lead to corrosion of the inlet and outlet components.	no	STOP	STOP	yes	Condition Monitoring	WO	STOP	STOP	YES	**Plan Maintenance**	no	STOP	STOP	STOP
		3.2 Abrasive Particles: Presence of abrasive particles or sediments in the fluid flow can cause erosion of the inlet and outlet surfaces over time.	no	STOP	STOP	yes	Condition Monitoring	WO	STOP	STOP	YES	**Plan Maintenance**	no	STOP	STOP	STOP
4	Inaccurate Reading	4.1 Internal Damage: Internal components of the pressure gauge, such as the bourdon tube or dial mechanism, may become damaged due to wear and tear, excessive pressure, or mechanical shock.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	STOP	STOP	HID	YES	failure finding	STOP
		4.2 Calibration Drift: Over time, the accuracy of the pressure gauge may drift due to factors like environmental conditions, vibration, or exposure to corrosive substances, leading to incorrect pressure readings.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	STOP	STOP	HID	YES	failure finding	STOP

5	Mechanical Damage	5.1 Physical Impact: Accidental impact or mechanical shock to the pressure gauge, such as dropping heavy objects on it or bumping into it during maintenance activities, can cause mechanical damage.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	NO	NID	NO	NO	evident	One-time change
		5.2 Excessive Pressure: Exposure to pressures beyond the gauge's specified range or sudden pressure spikes in the system can overload the internal components, leading to mechanical failure.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	NO	NID	NO	NO	evident	One-time change
6	Calibration Drift	6.1 Environmental Factors: Changes in temperature, humidity, or atmospheric pressure can affect the properties of the pressure gauge's internal components, leading to calibration drift over time.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		6.2 Wear and Tear: Normal wear and tear on the gauge's mechanical or electronic components, such as the bourdon tube or sensing element, can cause gradual changes in its calibration accuracy.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
7	Plugged/choked inlet	7.1 Spring Fatigue: Over time, the spring in the pressure relief valve may weaken or lose elasticity due to cyclic loading, high temperatures, or corrosion, resulting in inadequate relief pressure.	no	STOP	STOP	NO	NID	WO	STOP	STOP	YES	**Plan Maintenance**	STOP	STOP	STOP	STOP
		7.2 Buildup of Deposits: Accumulation of debris, scale, or sediment within the pressure relief valve can obstruct its mechanism, preventing proper operation and release of excess pressure.	no	STOP	STOP	NO	NID	WO	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
8	Plugged/choked outlet	8.1 Mechanical Obstruction: Accumulation of debris, corrosion, or foreign objects in the valve's internal passages or seat may prevent it from fully opening during overpressure conditions.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	STOP	STOP	EVD	YES	failure finding	STOP
		8.2 Spring Failure: Weakening or failure of the valve's spring mechanism, which provides the force necessary to open the valve, can lead to insufficient force to overcome the pressure.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	STOP	STOP	EVD	YES	failure finding	STOP

7	External leak/rupture	9.1 Seal Degradation: Deterioration or damage to the valve seals due to age, chemical exposure, or mechanical wear can result in leakage.	no	STOP	STOP	NO	NID	WO	STOP	STOP	YES	Plan Maintenance	yes	STOP	STOP	STOP
		9.2 Seat Misalignment: Misalignment of the valve seat or disc caused by improper installation, mechanical stress, or system vibration may lead to inadequate sealing and leakage.	no	STOP	STOP	NO	NID	WO	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
8	Plugged/choked inlet	10.1 Corrosion and Rust: Exposure to moisture and corrosive elements can cause the drain valve components, such as seals, threads, or metal parts, to corrode or rust over time, leading to degradation and malfunction.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		10.2 Sediment Buildup: Accumulation of debris, scale, or sediment within the drain valve can obstruct its operation, preventing proper opening or closure and resulting in blockages or leaks.	no	STOP	STOP	NO	**NID**	WO	STOP	STOP	YES	Plan Maintenance	no	STOP	STOP	STOP
7	External leak/rupture.	11.1 Seal Degradation: Deterioration or damage to the valve seals due to age, chemical exposure, or mechanical wear can result in leakage.	YES	LOW	run-to-failure	NO	NID	WO	STOP	STOP	STOP	**STOP**	STOP	STOP	STOP	STOP
		11.2 Corrosion: Corrosive substances present in the fluid or environment can corrode the valve components, compromising their integrity and causing leakage.	YES	LOW	run-to-failure	NO	NID	WO	STOP	STOP	STOP	**STOP**	STOP	STOP	STOP	STOP
8	Plugged/choked outlet	12.1 Debris Accumulation: Accumulation of dirt, sediment, or foreign objects in the valve passage can obstruct the flow path and prevent proper valve operation.	no	STOP	STOP	NO	**NID**	WO	NO	Consider Redesign	STOP	STOP	STOP	STOP	STOP	STOP
		12.2 Scaling: Scaling due to mineral deposits or corrosion products can form inside the valve, narrowing the passage and impeding fluid flow.	no	STOP	STOP	NO	**NID**	WO	NO	Consider Redesign	STOP	STOP	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group: Propulsion Function Group
System: Diesel Engine
Subsystem: Compressed Air System
Sub-Subsystem: Starting Main Engine

Equipment ID: CA-AR-01
Equipment Name: Air Receiver
Drawing: Compressed Air System

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Inspect and repair damaged wires and secure all connections.	CM	1.1 1.2	Rendah	Rendah	500 hours and/or Performed on: Regular electrical inspections When faults or short circuits occur	-	Performed by a mechanic. Repairs should be done immediately if any damage is found.
Lubricate parts, inspect seals, and replace worn components.	PM	2.1 2.2	Rendah	Rendah	1000 hours and/or Performed on: Routine maintenance schedule When leaks or wear are detected	-	Follow manufacturer/vendor recommendations. Repairs should be done immediately if any damage is found.
Apply corrosion-resistant coatings and clean corrosion products.	CM/PM	3.1 3.2	Rendah	Rendah	2000 hours and/or Performed on: Annual maintenance When corrosion is detected	-	Performed by a mechanic. Follow manufacturer/vendor recommendations.
Calibrate the gauge and install protective covers.	FF	4.1 4.2	Rendah	Rendah	1000 hours and/or Performed on: Routine calibration schedule When inaccurate readings are observed	-	Follow manufacturer/vendor recommendations. Repairs should be done immediately if any damage is found.
Install guards and test pressure limiters.	OTC	5.1 5.2	Rendah	Rendah	2000 hours and/or Performed on: Annual inspection When pressure anomalies are detected	-	Performed by a mechanic. Repairs should be done immediately if any damage is found.

Calibrate the gauge per manufacturer guidelines.	PM	6.1 6.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Scheduled calibration When calibration drift is observed	-	Follow manufacturer/vendor recommendations. Performed by a mechanic.

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group	**Equipment ID:**	CA-AR-01
System:	Diesel Engine	**Equipment Name:**	Air Receiver
Subsystem:	Compressed Air System	**Drawing:**	Compressed Air System
Sub-Subsystem:	Starting Main Engine		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Test and recertify valve set pressure and performance.	FF	8.1 8.2	Rendah	Rendah	2000 hours and/or Performed on: Annual testing schedule When relief pressure issues are observed	-	Performed by a mechanic. Repairs should be done immediately if any damage is found

CM	Condition Monitoring	0
PM	Planned Maintenance	0
CM/PM	Combination of CM and PM	0
FF	Failure Finding	1
OTC	One-time Change	0
RTF	Run-to-Failure	0
AAET	Any Applicable and Effective Task	0
	SUM	**1**

SUMMARY OF MAINTENANCE TASK

CATEGORY C

Functional Group:	Propulsion Function Group		**Equipment ID:**	CA-AR-01
System:	Diesel Engine		**Equipment Name:**	Air Receiver
Subsystem:	Compressed Air System		**Drawing:**	Compressed Air System
Sub-Subsystem:	Starting Main Engine			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Clean, lubricate, reassemble, and test the valve.	PM	7.1 7.2	Rendah	Rendah	2000 hours and/or Performed on: Routine maintenance schedule When valve performance issues are detected	-	Performed by a mechanic. Repairs should be done immediately if any damage is found
Clean, lubricate, and reassemble the drain valve.	PM	9.1 9.2	Rendah	Rendah	1000 hours and/or Performed on: Routine maintenance schedule When blockage or malfunction is detected	-	Follow manufacturer/vendor recommendations. Performed by a mechanic.
Clean, lubricate, and reassemble the drain valve	PM	10.1 10.2	Rendah	Rendah	1000 hours and/or Performed on: Routine maintenance schedule When blockage or malfunction is detected	-	Repairs should be done immediately if any damage is found. Follow manufacturer/vendor recommendations.
Replace seals, clean, and lubricate valve components.	RTF	11.1 11.2	Rendah	Rendah	2000 hours and/or Performed on: Annual maintenance When leaks or seal degradation are observed	-	Follow manufacturer/vendor recommendations. Performed by a mechanic.
Flush the valve and perform operational checks.	AAET	12.1 12.2	Rendah	Rendah	1000 hours and/or Performed on: Routine cleaning schedule When operational issues or blockages are detected	-	Performed by a mechanic. Repairs should be done immediately if any damage is found.

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-AHU-01
System:	Diesel Engine	**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	serves as the central component responsible for the circulation, temperature regulation, and filtration of air throughout the vessel.	Primary	1.1	Failed to compromised ventilation and cooling performance (Total Failure)
			1.2	inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-AHU-01
System:	Diesel Engine	**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	rotor	Overheats	**1.1 Moisture ingress: Entry of moisture into the motor winding can compromise insulation integrity and cause breakdown.**	Random	1. Formation of hotspots 2. Potential arcing	1.1 Failed to compromised ventilation and cooling performance
			1.2 Voltage spikes: Sudden voltage surges can exceed the insulation's dielectric strength, leading to insulation breakdown.	Random		
		Worn	**2.1 Lack of lubrication: Inadequate lubrication of the motor bearings can lead to increased friction and heat generation, accelerating wear and potentially causing bearing failure.**	Wear-out	1. inncreased friction and heat generation within the bearings 2. Abrasion and scoring of bearing surfaces due to foreign particle ingress	1.1 Failed to compromised ventilation and cooling performance
			2.2 Contamination by foreign particles: Entry of dirt, dust, or other foreign particles into the bearing assembly can cause abrasion and scoring of bearing surfaces, leading to premature wear and eventual failure.	Wear-out		
			3.1 Exposure to moisture and corrosive elements: Moisture and corrosive elements can infiltrate the motor's electrical components, such as terminals and wiring, leading to	Wear-out		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Leaking	**degradation of insulation materials and increased conductivity between electrical paths.**		1. Increased risk of short circuits 2. Accumulation of dust and debris on electrical connections	1.1 Failed to compromised ventilation and cooling performance
			3.2 Build-up of conductive contaminants: Over time, dust, dirt, and other conductive contaminants can accumulate on electrical connections, creating a pathway for electricity to flow where it shouldn't, increasing resistance, and generating heat.	Wear-out		
2	Coils	Overheats	**4.1 Overloading: Operating the coils beyond their rated capacity can lead to excessive heat generation and overheating.**	Random	1. Localized temperature rise 2. Thermal expansion	1.2 inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)
			4.2 Poor ventilation: Inadequate airflow around the coils restricts heat dissipation, causing temperature buildup.	Wear-out		
		Corroded	**5.1 Exposure to corrosive environments: Exposure of the coils to corrosive environments, such as saltwater or chemical fumes, can lead to Corroded of coil surfaces and degradation of coil materials.**	Wear-out	1. Formation of rust or Corroded pits on coil surfaces 2. Thinning or weakening of coil material due to Corroded	1.1 Failed to compromised ventilation and cooling performance
			5.2 Inadequate protective coatings or sealing: Lack of proper protective coatings or sealing on coil surfaces leaves them vulnerable to Corroded from environmental exposure, accelerating material degradation.	Random		
	-		**6.1 Low refrigerant level due to leakage:**			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Leaking	**6.1 Low refrigerant level due to leakage: Refrigerant leakage from the coils can result in a decreased heat absorption capacity, causing the temperature of the coils to drop below freezing point and leading to ice formation.**	Wear-out	1. Reduced heat absorption capacity of coils due to low refrigerant levels 2. Hindered airflow and decreased heat transfer efficiency caused by dirt accumulation	1.2 inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)
			6.2 Blockage of airflow due to dirt accumulation: Accumulation of dirt, dust, and other debris on the coils can obstruct airflow, reducing heat transfer efficiency and causing the coil surface temperatures to drop, leading to freezing.	Wear-out		
3	Air Filter	Clogging	**7.1 Accumulation of airborne particles and debris: Continuous operation of the air filter in dusty or debris-laden environments leads to the accumulation of airborne particles and debris on the filter media, gradually reducing airflow.**	Wear-out	1. Gradual reduction in airflow through the filter media 2. Increased pressure drop across the filter	1.1 Failed to compromised ventilation and cooling performance
			7.2 Inadequate filter maintenance or replacement intervals: Failure to perform regular filter maintenance or replace clogged filters according to recommended intervals allows debris accumulation to reach levels that impede airflow and filtration efficiency.	Wear-out		
		Cracked	**8.1 High-pressure differential: Excessive pressure differential across the filter due to clogging or restricted airflow can lead to structural failure.**	Wear-out	1. Deformation or collapse 2.Tearing or ripping	1.2 inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)
			8.2 Mechanical damage: Impact or mishandling during installation or maintenance can cause structural damage to the filter.	Random		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Corroded	**9.1 Exposure to corrosive chemicals:** **Exposure to corrosive chemicals in the air or surrounding environment can lead to the deterioration of filter media, resulting in tears and holes that compromise filtration efficiency.**	Wear-out	1. Deterioration of filter media, leading to increased bypass of contaminants 2. Blockage of filter media and potential contamination of the air supply	1.1 Failed to compromised ventilation and cooling performance
			9.2 Growth of mold and bacteria: **Mold and bacteria growth on the air filter can block filter media and impede airflow, reducing filtration efficiency and promoting the spread of airborne contaminants.Growth of mold and bacteria**	Wear-out		
4	Gear	Worn	**10.1 Inadequate lubricant quantity or quality:** **Insufficient lubricant quantity or use of low-quality lubricants in the gear assembly can result in inadequate lubrication film thickness, increasing friction and wear between gear surfaces.**	Wear-out	1. Increased friction and wear between gear surfaces 2. Formation of abrasive particles or debris in the gear assembly	1.2 inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)
			10.2 Contamination of lubricant by foreign particles: **Entry of dirt, dust, or other foreign particles into the gear lubricant can cause abrasive wear on gear surfaces and breakdown of lubricant film, leading to increased friction and heat generation.**	Wear-out		
		Misalignment	**11.1 Inadequate Lubrication:** **Insufficient lubrication between gear teeth leads to increased friction and accelerated wear.**	Wear-out	1. Surface Pitting and Scoring 2. Material Removal and Deformation	1.1 Failed to compromised ventilation and cooling performance
			11.2 Contamination: **Entry of abrasive particles or debris into the**	Wear-out		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			gear meshing area causes abrasive wear on gear teeth.	Wear-out		
		Leaking	**12.1 Lack of lubrication:** **Inadequate lubrication of gear components can lead to increased friction between gear teeth, accelerating wear and potentially causing mechanical failure.**	Wear-out	1. Increased friction between gear teeth 2.Abrasion and Corroded of gear surfaces due to the presence of contaminant	1.2 inadequate ventilation and reduced cooling efficiency, within capacity less than 6500 CFM (Partial Failure)
			12.2 Corroded due to chemical exposure: **Exposure to corrosive chemicals can deteriorate gear material, weakening the gear structure and increasing the risk of gear failure under load conditions.**	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

DIGITAL MARINE OPERATION & MAINTENANCE

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-AHU-01
System:	Diesel Engine	**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	rotor	Overheats	**Short circuits: Insulation breakdown can result in short circuits within the motor winding, causing sudden motor failure and system downtime.**	3	2	1	**Rendah-Menengah**	1. Monitoring of motor temperature and abnormal noises. 2. Visual inspection for signs of Corroded and moisture ingress. .	Regular cleaning and lubrication of rotor components. Implementing moisture barriers and Corroded-resistant coatings. Scheduled replacement of lubricants and bearings.
		Worn	**Bearing seizure and motor shaft immobilization: Severe wear or damage to the bearings can result in bearing seizure, causing the motor shaft to become immobilized and leading to sudden motor failure.**	2	3	2	**Rendah-Menengah**	1. Monitoring of motor temperature and abnormal noises. 2. Visual inspection for signs of Corroded and moisture ingress.	Regular cleaning and lubrication of motor bearings. Implementing moisture barriers and Corroded-resistant coatings. Scheduled replacement of lubricants and bearings.
		Leaking	**Sudden motor failure, potentially leading to system downtime and safety hazards: Electrical failure within the motor can result in the sudden cessation of motor operation, leading to system downtime and potential safety hazards, especially if the motor is critical for essential ship functions..**	3	3	1	**Menengah**	1. Regular inspection for signs of moisture ingress and Corroded on electrical components 2. Monitoring of electrical connections for signs of overheating and voltage fluctuations..	Implementing moisture barriers and Corroded-resistant coatings. Regular cleaning and inspection of electrical connections. Scheduled replacement of motor windings and insulation.
		Overheats	**Coil damage: Prolonged overheating can cause damage to coil insulation and**	3	1	1	**Rendah-**	1. Visual inspection of coil surfaces for dirt accumulation. 2. Visual inspection for signs of	Regular cleaning and maintenance of coil surfaces. Implementing UV-C or other disinfection methods. Implementing

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
	Coils		**materials, compromising coil integrity and performance.**				**Menengah**	microbial growth and musty odors.	protective coatings and Corroded-resistant materials.
2		Corroded	**Reduced coil efficiency and heat transfer capacity: Corroded-induced degradation of coil surfaces reduces their efficiency in transferring heat, leading to decreased system performance and potentially causing overheating.**	3	1	2	**Rendah-Menengah**	1. Visual inspection for signs of Corroded and structural weakness. 2. Regular inspection for signs of Corroded and pitting on coil surfaces.	Implementing protective coatings and Corroded-resistant materials.Implementing Corroded-resistant coatings and materials for coils. Implementing UV-C or other disinfection methods.
	-	Leaking	**Low refrigerant level due to leakage: Refrigerant leakage from the coils can result in a decreased heat absorption capacity, causing the temperature of the coils to drop below freezing point and leading to ice formation.**	1	1	1	**Rendah**	1. Monitoring of refrigerant levels and pressure differentials across the coil. 2. Visual inspection for signs of dirt accumulation and temperature differentials across the coil.	Regular inspection and maintenance to detect and repair refrigerant leaks.Regular cleaning and maintenance of coil surfaces and surrounding areas. Implementing UV-C or other disinfection methods.
	Air Filter	Clogging	**Decreased indoor air quality or cooling system efficiency: Reduced airflow and filtration efficiency resulting from clogged filters lead to decreased indoor air quality or cooling system performance, potentially causing discomfort or health issues for occupants.**	2	1	2	**Rendah**	1. Monitoring of pressure differentials across the filter 2. Visual inspection for signs of microbial growth and musty odors. 3. Regular inspection for signs of Corroded and structural weakness..	Regular cleaning or replacement of air filters. Implementing UV-C or other disinfection methods.Implementing Corroded-resistant filter materials and housings.
3		Cracked	**Loss of filtration efficiency: Structural failure compromises the integrity of the filter, reducing its ability to capture airborne contaminants effectively.**	3	2	3	**Rendah-Menengah**	1. Monitoring of pressure differentials across the filter 2. Visual inspection for signs of microbial growth and musty odors..	Regular cleaning or replacement of air filters. Implementing UV-C or other disinfection methods.Implementing Corroded-resistant filter

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda (10)	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
									materials and housings.
		Corroded	**Increased bypass of contaminants and reduced filtration efficiency: Damage to the air filter media allows contaminants to pass through the filter, reducing its ability to capture airborne particles and potentially compromising indoor air quality.**	2	1	1	**Rendah**	1. Regular inspection for signs of physical damage and structural weakness. 2. Visual inspection for signs of microbial growth and musty odors.	Implementing Corroded-resistant filter materials and housings.Implementing UV-C or other disinfection methods. Implementing Corroded-resistant filter materials and housings.
4	Gear	Worn	**Progressive wear and degradation of gear teeth: Continued friction and wear between gear surfaces result in progressive damage and degradation of gear teeth, leading to reduced gear efficiency and potential gear failure.**	3	1	1	**Rendah-Menengah**	1. Monitoring of gear temperature and vibration levels. 2. Visual inspection for signs of contamination and wear on gear surfaces.	Scheduled lubrication and inspection of gear components. Implementing proper sealing and contamination prevention measures.Implementing Corroded-resistant coatings and materials for gears.
		Misalignment	**Reduced Gear Efficiency: Tooth wear decreases gear efficiency and transmission accuracy, resulting in reduced system performance.**	2	3	2	**Rendah-Menengah**	1. Monitoring of gear temperature and vibration levels. 2. Visual inspection for signs of contamination and wear on gear surfaces.	Scheduled lubrication and inspection of gear components.Implementing proper sealing and contamination prevention measures.Implementing Corroded-resistant coatings and materials for gears.
		Leaking	**.Gradual loss of gear efficiency and potential mechanical failure: Increased wear and deterioration of gear components lead to a gradual loss of gear efficiency, potentially resulting in gear failure and system downtime.**	3	3	1	**Menengah**	1. Monitoring of gear temperature and vibration levels. 2. Visual inspection for signs of contamination and wear on gear surfaces.	Implement a routine maintenance schedule to flush or clean the valve to remove accumulated debris, sediment, or scale Scheduled lubrication and inspection of gear

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-AHU-01
System:	Diesel Engine	**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	rotor	Overheats	3	2	Rendah-Menengah	Regularly test insulation resistance to detect early signs of moisture ingress and address them promptly.	1	Rendah-Menengah	-
		Worn	2	3	Rendah-Menengah	improve or replace seals to prevent the ingress of dirt, dust, or other particles into the bearing assembly.	2	Rendah-Menengah	-
		Leaking	3	3	Menengah	Ensure proper sealing of terminals and wiring to prevent moisture ingress.	2	Rendah-Menengah	-

	Coils	Overheats	3	1	**Rendah-Menengah**	Establish and enforce operational limits to prevent overloading of the coils.	1	**Rendah-Menengah**	-
2		Corroded	3	1	**Rendah-Menengah**	Apply corrosion-resistant coatings to coil surfaces to protect them from corrosive environments.	1	**Rendah-Menengah**	-
	-	Leaking	1	1	**Rendah**	Regularly check and replenish refrigerant levels to maintain proper heat absorption capacity.	1	**Rendah**	-
	Air Filter	Clogging	2	1	**Rendah**	Establish and adhere to a regular filter maintenance and replacement schedule.	1	**Rendah**	-

3		Cracked	3	2	**Rendah-Menengah**	nstall pressure sensors to monitor the pressure differential across the filter and take corrective action as needed.	1	**Rendah-Menengah**	-
		Corroded	2	1	**Rendah**	Implement a routine cleaning schedule to prevent the growth of mold and bacteria on filters.	1	**Rendah**	-
	Gear	Worn	3	1	**Rendah-Menengah**	Schedule regular changes of lubricant to remove contaminants and maintain its effectiveness.	1	**Rendah-Menengah**	-
4		Misalignment	2	3	**Rendah-**	mplement protective measures to prevent the entry of abrasive	2	**Rendah-**	-

4			2	3	**Menengah**	particles or debris into the gear meshing area.	2	**Menengah**	
		Leaking	3	3	**Menengah**	Ensure regular application of lubricant to gear components according to the maintenance schedule.	2	**Rendah-Menengah**	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Overheats	1.1 Moisture ingress: Entry of moisture into the motor winding can compromise insulation integrity and cause breakdown.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		1.2 Voltage spikes: Sudden voltage surges can exceed the insulation's dielectric strength, leading to insulation breakdown.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
2	Worn	2.1 Lack of lubrication: Inadequate lubrication of the motor bearings can lead to increased friction and heat generation, accelerating wear and potentially causing bearing failure.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Contamination by foreign particles: Entry of dirt, dust, or other foreign particles into the bearing assembly can cause abrasion and scoring of bearing surfaces, leading to premature wear and eventual failure.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
3	Leaking	3.1 Exposure to moisture and corrosive elements: Moisture and corrosive elements can infiltrate the motor's electrical components, such as terminals and wiring, leading to degradation of insulation materials and increased conductivity between electrical paths.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		3.2 Build-up of conductive contaminants: Over time, dust, dirt, and other conductive contaminants can accumulate on electrical connections, creating a pathway for electricity to flow where it shouldn't, increasing resistance, and generating heat.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
4	Overheats	4.1 Overloading: Operating the coils beyond their rated capacity can lead to excessive heat generation and overheating.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

4		4.2 Poor ventilation: Inadequate airflow around the coils restricts heat dissipation, causing temperature buildup.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
5	Corroded	5.1 Exposure to corrosive environments: Exposure of the coils to corrosive environments, such as saltwater or chemical fumes, can lead to Corroded of coil surfaces and degradation of coil materials.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	STOP	STOP	EVD	NO	evident	One-time change
		5.2 Inadequate protective coatings or sealing: Lack of proper protective coatings or sealing on coil surfaces leaves them vulnerable to Corroded from environmental exposure, accelerating material degradation.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	no	NID	EVD	NO	evident	One-time change
6	Leaking	6.1 Low refrigerant level due to leakage: Refrigerant leakage from the coils can result in a decreased heat absorption capacity, causing the temperature of the coils to drop below freezing point and leading to ice formation.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		6.2 Blockage of airflow due to dirt accumulation: Accumulation of dirt, dust, and other debris on the coils can obstruct airflow, reducing heat transfer efficiency and causing the coil surface temperatures to drop, leading to freezing.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
7	Clogging	7.1 Accumulation of airborne particles and debris: Continuous operation of the air filter in dusty or debris-laden environments leads to the accumulation of airborne particles and debris on the filter media, gradually reducing airflow.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

		7.2 Inadequate filter maintenance or replacement intervals: Failure to perform regular filter maintenance or replace clogged filters according to recommended intervals allows debris accumulation to reach levels that impede airflow and filtration efficiency.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
8	Cracked	8.1 High-pressure differential: Excessive pressure differential across the filter due to clogging or restricted airflow can lead to structural failure.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		8.2 Mechanical damage: Impact or mishandling during installation or maintenance can cause structural damage to the filter.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
9	Corroded	9.1 Exposure to corrosive chemicals: Exposure to corrosive chemicals in the air or surrounding environment can lead to the deterioration of filter media, resulting in tears and holes that compromise filtration efficiency.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	EVD	NO	evident	One-time change
		9.2 Growth of mold and bacteria: Mold and bacteria growth on the air filter can block filter media and impede airflow, reducing filtration efficiency and promoting the spread of airborne contaminants.Growth of mold and bacteria	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	EVD	NO	evident	One-time change
10	Worn	10.1 Inadequate lubricant quantity or quality: Insufficient lubricant quantity or use of low-quality lubricants in the gear assembly can result in inadequate lubrication film thickness, increasing friction and wear between gear surfaces.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

10		10.2 Contamination of lubricant by foreign particles: Entry of dirt, dust, or other foreign particles into the gear lubricant can cause abrasive wear on gear surfaces and breakdown of lubricant film, leading to increased friction and heat generation.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
11	Misalignment	11.1 Inadequate Lubrication: Insufficient lubrication between gear teeth leads to increased friction and accelerated wear.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		11.2 Contamination: Entry of abrasive particles or debris into the gear meshing area causes abrasive wear on gear teeth.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
12	Leaking	12.1 Lack of lubrication: Inadequate lubrication of gear components can lead to increased friction between gear teeth, accelerating wear and potentially causing mechanical failure.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		12.2 Corroded due to chemical exposure: Exposure to corrosive chemicals can deteriorate gear material, weakening the gear structure and increasing the risk of gear failure under load conditions.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-AHU-01
System:	Diesel Engine	**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
replace the filter with a corrosion-resistant one, clean the filter housing, and disinfect the area using UV-C methods to prevent further contamination.	CM/PM	7.1 7.2	Rendah	Rendah	200 hours and/or Performed on: Filter inspection or clogging When filter damage or contamination occurs	-	Follow manufacturer recommendations
immediately replace it with a corrosion-resistant alternative, clean the housing, and use UV-C disinfection to ensure cleanliness.	CM/PM	8.1 8.2	Rendah-Menengah	Rendah-Menengah	200 hours and/or Performed on: Filter damage or performance issues When a filter is found to be damaged or contaminated	-	Follow manufacturer recommendations
replace them with corrosion-resistant ones, clean the housing, and disinfect using UV-C methods to maintain hygiene.	OTC	9.1 9.2	Rendah	Rendah	200 hours and/or Performed on: Filter inspection or contamination check When filter corrosion or damage is detected	-	Follow manufacturer recommendations

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group		**Equipment ID:**	CO-AHU-01
System:	Diesel Engine		**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System		**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
immediately clean and re-lubricate the rotor, apply a moisture barrier, and replace any corroded or damaged bearings.	CM/PM	1.1 1.2	Rendah-Menengah	Rendah-Menengah	500 hours and/or Performed on: Damage or performance degradation detection test When corrosion or bearing damage occurs	-	Performed by an experienced technician
promptly clean and re-lubricate the bearings, apply a corrosion-resistant coating, and replace the damaged bearings.	CM/PM	2.1 2.2	Rendah-Menengah	Rendah-Menengah	250 hours and/or Performed on: Bearing inspection or performance issues When bearing corrosion or damage is detected	-	Adhere to manufacturer recommendations
clean and lubricate rotor components, repair moisture barriers, apply corrosion-resistant coatings, and replace failed lubricants and bearings	CM/PM	3.1 3.2	Menengah	Rendah-Menengah	1000 hours and/or Performed on: Implementing moisture barriers and corrosion-resistant coatings:	-	Performed by a skilled mechanic to ensure all components are functioning optimally.

lubricate and inspect the gears, apply proper seals, and replace damaged gears with corrosion-resistant alternatives.	CM/PM	10.1 10.2	**Rendah-Menengah**	**Rendah-Menengah**	1000 hours and/or Performed on: Gear inspection or performance review When gear damage or wear is detected	-	Carried out by a mechanic
re-lubricate the gear components, ensure proper sealing to prevent contamination, and replace damaged gears with corrosion-resistant materials.	CM/PM	11.1 11.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours and/or Performed on: Gear component inspection or lubrication check When gears are found to be damaged or contaminated	-	Prompt replacement of damaged gears
flush or clean the valve to remove debris, re-lubricate the gear components, apply proper sealing, and replace any damaged parts with corrosion-resistant materials.	CM/PM	12.1 12.2	**Menengah**	**Rendah-Menengah**	1000 hours and/or Performed on: Valve inspection or maintenance schedule When valve debris or gear damage is detected	-	Performed by a trained mechanic

SUMMARY OF MAINTENANCE TASK

CATEGORY C

Functional Group:	Propulsion Function Group		**Equipment ID:**	CO-AHU-01
System:	Diesel Engine		**Equipment Name:**	Air Handling Unit
Subsystem:	Cooling System		**Drawing:**	Cooling System
Sub-Subsystem:	Air Handling Unit System			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
clean and disinfect the coils using UV-C methods, apply a protective coating, and replace any damaged coil sections with corrosion-resistant materials.	CM/PM	4.1 4.2	Rendah-Menengah	Rendah-Menengah	1000 hours and/or Performed on: Coil condition assessment When coil contamination or damage occurs	-	Immediate replacement of damaged coil
apply protective coatings to the affected coils, replace damaged coil sections with corrosion-resistant materials, and disinfect the area using UV-C methods.	OTC	5.1 5.2	Rendah-Menengah	Rendah-Menengah	500 hours and/or Performed on: Coil damage or contamination inspection When damage or corrosion is detected	-	Adhere to manufacturer guidelines
immediately repair the leak, clean and disinfect the coil surfaces and surrounding areas using UV-C methods, and ensure proper sealing of the repaired area.	CM/PM	6.1 6.2	Rendah	Rendah	200 hours and/or Performed on: Filter damage or performance issues When a filter is found to be damaged or contaminated	-	Carried out by an experienced technician

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Circulate coolant throughout various components of the ship's cooling system, within specification Capacity 100 M3/H, Head 20m. "	Primary	1.1	No pumping water to initiate coolant circulation (Total Failure)
			1.2	Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	Pump Casing	Corroded	**1.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.**	Random	1. . Reduced Structural Integrity 2. Decreased Pump Efficiency	1.2Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			1.2 Age and Wear: Like any other equipment on a ship, Cooling pumps and their casings are subject to wear and tear over time. With age, the protective coatings on the casing may degrade, making it more susceptible to corrosion	Wear-out		
		Fractured	**2.1 Mechanical Stress: The casing may experience mechanical stress due to factors such as vibration, shock loads, or impacts during normal operation or in rough sea conditions. Over time, this stress can lead to fatigue and eventually fracture of the casing.**	Random	1. Reduced Pump Efficiency 2. Immediate Loss of Functionality	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			2.2 Overloading: If the Cooling pump is subjected to loads beyond its design capacity, such as excessive pressure or flow rate, it can put undue stress on the casing, leading to fracture.	Random		
			3.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can	Random		1.2 Pumping water to suboptimal

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Deformed	**cause deformation, especially if the casing material is not sufficiently robust.**		1. Reduced Pump Efficiency 2. Pump Operation with Vibration and Noise	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			3.2 Corrosion: Continuous exposure to seawater and other corrosive substances can lead to the corrosion of metal casings over time. Corrosion weakens the structural integrity of the casing, making it susceptible to deformation.	Wear-out		
2	Impeller	Corroded	**4.1 High Temperatures: Elevated temperatures in the Cooling area, either due to the pump's operation or nearby machinery, can accelerate corrosion processes, especially if combined with other factors like saltwater exposure or chemical contamination.**	Wear-out	1. Reduced Efficiency 2. Material Weakening	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			4.2 Saltwater Exposure: Ships operate in a highly corrosive environment due to constant exposure to saltwater. If the Cooling pump is not adequately protected or made from corrosion-resistant materials, saltwater exposure can lead to corrosion of the impeller over time.	Wear-out		
		Fractured	**5.1 Material Fatigue: Continuous operation of the Cooling pump impeller can subject it to repeated cycles of stress, leading to material fatigue over time. This fatigue can weaken the material structure of the impeller, eventually resulting in cracks or fractures.**	Wear-out	1. Reduced Pump Efficiency 2.. Immediate Loss of Functionality	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			5.2 Impact or Mechanical Damage: External factors such as collisions, debris ingestion, or abrasive wear can cause physical damage to the impeller, resulting in cracks or fractures. Impact from foreign objects or sudden changes in operating conditions can lead to immediate failure or accelerate	Random		
			6.1 Mechanical Stress: Continuous operation of the Cooling pump can subject the impeller			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
	-	Deformed	**of the Cooling pump can subject the impeller to mechanical stress, especially if it encounters high fluid flow rates or pressure. Over time, this stress can cause the impeller to deform, particularly in areas where the material is weaker or subjected to uneven loading.**	Wear-out	1. Vibration and Noise 2. Reduced Pump Efficiency	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			6.2 Overloading: Excessive loads on the Cooling pump system, such as sudden surges in fluid volume or pressure, can exceed the impeller's design limits and cause deformation. This can occur due to factors like blockages in the pump, changes in fluid viscosity, or improper pump operation.	Random		
3	Bearing	Cracked	**7.1 Impact or Mechanical Damage: External factors like impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the bearings, resulting in cracks.**	Random	1. Increased Operating Temperature 2. Structural Damage	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			7.2 Fatigue: Over time, repeated stress cycles experienced by the bearings during pump operation can weaken the material, leading to microscopic cracks that propagate and eventually result in visible cracks.	Wear-out		
		Contaiminated	**8.1 Ingress of Foreign Particles: Small particles such as dirt, sand, debris, or rust can enter the bearing housing, especially if the pump is operating in a harsh environment or if seals are compromised. These particles can contaminate the lubricant and cause abrasive wear on the bearing surfaces.**	Random	1. Increased Friction and Wear 2. Reduced Efficiency	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			8.2 Oil or Fuel Leakage: Leakage of oil or fuel from nearby machinery or systems can contaminate the bearing. Oil or fuel contamination can degrade the lubricant's effectiveness, leading to increased friction	Random		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			and wear on the bearing surfaces.			
		Fractured	**9.1 .Overloading: Excessive loads on the bearing beyond its designed capacity can lead to fractures. This can happen due to sudden surges in pump operation, such as during startup or when pumping against high resistance, causing stress concentrations and eventual fracture.**	Random	1. Immediate Loss of Functionality 2. Vibration and Noise	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			9.2 Fatigue: Prolonged cyclic loading and unloading of the bearing during normal pump operation can lead to fatigue failure over time. This is particularly common in bearings subjected to repeated stress cycles, causing microscopic cracks to form and propagate until complete fracture occurs.	Wear-out		
4	Shaft Seal Cover	Corroded	**10.1 Exposure to Corrosive Substances: The seal may come into contact with corrosive substances present in the Cooling water, such as saltwater, chemicals, or pollutants. Prolonged exposure to these corrosive agents can degrade the seal material and lead to corrosion.**	Wear-out	1. Corrosion weakens the structural integrity 2. Reduced Seal Performance	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			10.2 High Temperatures and Pressure: Elevated temperatures and pressures within the Cooling pump system can accelerate corrosion processes, particularly if the seal material is not resistant to these conditions.	Wear-out		
		Fractured	**11.1 Material Fatigue: Over time, repeated stress cycles can weaken the seal material, leading to microscopic cracks that propagate and eventually result in a fracture. This fatigue can occur due to the cyclical pressure changes experienced during pump operation.**	Wear-out	1. fractured seal compromises 2. Reduced Seal Performance	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			11.2 Impact or Mechanical Damage: External factors such as impacts from debris or improper handling during maintenance			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			Improper handling during maintenance procedures can cause mechanical damage to the seal, resulting in fractures.	Random		
		Worn	**12.1 Abrasion: Continuous contact between the seal and rotating shaft can lead to abrasive wear over time. Particles present in the Cooling water, such as sand, sediment, or debris, can cause abrasive damage to the seal surface, leading to wear**	Wear-out	1. Reduced Pump Performance 2.Vibration and Noise	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			12.2 Corrosion: Exposure to corrosive substances in the Cooling water, such as saltwater or chemicals, can corrode the seal material, leading to localized material degradation and wear. Corrosion weakens the seal's structural integrity and can accelerate wear, particularly in areas with high stress	Wear-out		
	Shaft	Corroded	**13.1 Improper Material Selection: Choosing materials for the shaft that are not resistant to corrosion or incompatible with the Cooling environment can promote corrosion and accelerate its progression.**	Wear-in	1. Reduced Strength 2. Impeller Misalignment	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			13.2 High Humidity and Temperature: Elevated humidity levels and fluctuating temperatures in the Cooling area can create conducive conditions for corrosion to occur on the shaft surface.	Wear-out		
5		Fractured	**14.1 Fatigue: Prolonged cyclic loading and unloading of the shaft during pump operation can lead to fatigue failure, causing microscopic cracks to form and propagate over time until a fracture occurs.**	Wear-out	1. Loss of Functionality 2.Immediate Loss of Functionality	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			14.2 Corrosion: Corrosive substances present in the Cooling water can degrade the shaft material, reducing its structural integrity and making it more susceptible to fracture failure.	Wear-out		capacity less than 100 M3/H (Partial Failure)
		Worn	**15.1 Abrasion: Continuous contact with abrasive particles present in the Cooling water, such as sand, sediment, or debris, can gradually wear down the surface of the shaft. This abrasion occurs over time and can lead to the thinning of the shaft diameter or the formation of grooves and pits on its surface.**	Wear-out	1. Reduced Efficiency 2.Seal Leakage	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			15.2Corrosion: Exposure to corrosive substances present in the Cooling water, such as saltwater or chemicals, can corrode the shaft material, leading to localized wear and pitting. Corrosion-induced wear weakens the shaft's structural integrity and accelerates its deterioration.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	Pump Casing	Corroded	**Pump Failure: Progressive corrosion of the pump casing weakens the structural integrity of the casing, eventually leading to catastrophic failure, pump malfunction, or complete breakdown, resulting in system downtime and loss of cooling capacity.**	1	2	2	**Rendah**	1. Leakage from cooling Pump 2. Decrease flow rate from cooling Pump	regular inspections, and use of corrosion-resistant materials are essential.
		Fractured	**Environmental Contamination: Fluid leakage from fractured pump casings can contaminate the surrounding environment, posing environmental hazards and safety risks to onboard personnel and marine ecosystems.**	3	1	1	**Rendah-Menengah**	1. Decrease flow rate from cooling Pump 2. No flow from cooling Pump	conduct regular inspections for signs of stress or damage, and ensure that the pump is operated within its design limits.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
		Deformed	**pump Malfunction: Deformed pump casings disrupt the normal operation of the circulating pump, resulting in reduced coolant circulation, loss of system efficiency, and potential pump failure, leading to cooling system downtime and operational disruptions..**	2	1	2	**Rendah**	1. Bend, crack, casing material 2. Decrease flow rate from cooling pump	conduct regular inspections, enhance material selection for casing construction, optimize operating conditions, improve installation practices, enhance maintenance procedures
2	Impeller	Corroded	**Increased Maintenance Costs: Corrosion-related pump failures necessitate costly repairs or replacements, as well as associated labor and downtime expenses, increasing maintenance costs and disrupting vessel operations.**	3	2	1	**Rendah-Menengah**	1. Decrease cooling pump performance 2. Visible corrosion 3. Increase noise and vibration	Assess the damage and consider replacing it with a corrosion-resistant impeller. Implement regular maintenance and consider applying corrosion-resistant coatings.
		Fractured	**Pump Failure: Fractured pump casings jeopardize the structural integrity of the circulating pump, resulting in pump malfunction, reduced coolant circulation, and eventual pump failure, leading to system downtime and loss of cooling capacity.**	2	3	2	**Rendah-Menengah**	1. Decrease cooling pump performance 2. No flow from cooling Pump	Prioritize the installation of a new, intact impeller and conduct regular inspections to prevent future fractures.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
	-	Deformed	**Increased Risk of heating: Inadequate cooling water removal due to impeller deformation increases the risk of heating in critical areas of the ship. This poses a safety hazard to the crew, passengers, and cargo, potentially compromising the vessel's seaworthiness and stability.**	1	1	2	Rendah	1. Decrease cooling pump performance 2. Noise and vibration	Regular inspections and monitoring can help detect deformities early on, preventing further issues.
	Bearing	Cracked	**Compromise structural integrity and load-bearing capacity, leading to progressive deterioration and eventual catastrophic failure, resulting in pump malfunction and system downtime.**	3	3	2	Menengah	1. Visbile abnormal crack 2. Vibration abnormal	Conduct routine visual and ultrasonic inspections to detect early signs of structural damage or load-bearing capacity compromise.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
3		Containinated	**Prone to premature failure due to accelerated wear, surface damage, and reduced load-bearing capacity, ultimately leading to pump malfunction, system downtime, and potentially catastrophic equipment failure.**	1	2	2	**Rendah**	1. Oil /substance analysis 2. Vibration and noise 3. Decrease efficiency	Apply surface treatments or coatings to reduce wear and protect against surface damage.
		Fractured	**Fluid leakage from fractured bearing can contaminate the surrounding environment, posing environmental hazards and safety risks to onboard personnel and marine ecosystems.**	2	3	1	**Rendah-Menengah**	1. Abnormal noise and vibration 2. Lubricant Leakage 3, Decrease flow rate and pressure	Regularly inspect and maintain seals to prevent fluid leakage from bearings.
	Shaft Seal Cover	Corroded	**Fluid Loss: Corroded shaft seal covers can lead to coolant or lubricant leakage from the pump assembly, resulting in reduced fluid levels, loss of system pressure, and diminished cooling or lubrication performance.**	2	1	1	**Rendah**	1. Decrease pressure and flowrate 2. Water leakage arround the pump	conduct a thorough inspection to assess the extent of corrosion and potential leaks.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
4		Fractured	**environmental Hazard: Fluid leakage from fractured shaft seal covers poses environmental hazards, particularly in marine environments, where leaked fluids may pollute waterways or cause harm to marine life.**	2	1	2	**Rendah**	1. Decrease pressure and flowrate 2. leakage of water	Conduct a thorough inspection of the surrounding components for any damage or wear.
		Worn	**Fluid Leakage: Worn shaft seal covers can contribute to increased fluid leakage from the pump assembly, resulting in loss of coolant or lubricant, reduced system performance, and potential damage to surrounding components due to inadequate lubrication or cooling.**	2	1	1	**Rendah**	1. Leakage of water 2. Reduced flow rate, decreased pressure, increase power consumption	Implement preventive maintenance, monitor seal performance, and apply proper lubrication.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
5	Shaft	Corroded	**Shaft Failure: Severe corrosion can weaken the shaft to the point of mechanical failure, resulting in pump malfunction, system downtime, and potential damage to other pump components.**	3	1	3	**Rendah-Menengah**	1. Friction and vibration 2. Decrease pump flowrate	Apply protective coatings and establish a preventive maintenance schedule to minimize future corrosion risks.
		Fractured	**Pump Failure: Fractured shafts result in the loss of mechanical integrity and functionality of the circulating pump, leading to system downtime, impaired cooling performance, and disruption of ship operations.**	2	2	1	**Rendah-Menengah**	1. cooling water output may have fractured metal shaft 2. Noise and vibration 3. Decrease pump flowrate 4. No flow form cooling pump	consider repairing or replacing it depending on the severity of the damage. Inspect other components for any additional damage or corrosion.
		Worn	**Reduced Efficiency: Worn shafts diminish the efficiency of the circulating pump, as increased friction and surface roughness lead to higher energy consumption, reduced flow rates, and decreased coolant circulation.**	2	1	2	**Rendah**	1. Abnormal vibration and noise 2. Reduce flow rate cooling pump 3. Temperature abnormal caused by friction	address a worn shaft in a cooling pump, promptly replace it with a new one and inspect surrounding components for wear or damage. Implement preventive maintenance measures and monitor pump performance

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	Pump Casing	Corroded	1	2	Rendah	Regular inspection and maintenance of pump casing. Monthly visual inspection; quarterly ultrasonic testing for corrosion detection.	1	Rendah	-
		Fractured	3	1	Rendah-Menengah	Implement containment measures and regular inspection. Bi-weekly visual inspection of pump casings and immediate action on detected fractures.	1	Rendah-Menengah	-
		Deformed	2	1	Rendah	Regular deformation checks and preventive maintenance. Monthly visual inspection; semi-annual structural integrity assessment.	1	Rendah	-
	Impeller	Corroded	3	2	Rendah-Menengah	Corrosion prevention measures and predictive maintenance. Monthly application of corrosion inhibitors; annual cost-benefit	1	Rendah-Menengah	-

						analysis of maintenance.			
2		Fractured	2	3	**Rendah-Menengah**	Enhanced monitoring and immediate repair upon fracture detection. Bi-weekly inspection; immediate corrective action on detected issues.	2	**Rendah-Menengah**	-
		Deformed	1	1	**Rendah**	Regular impeller inspection and replacement of deformed parts. Monthly visual inspection; annual thermal imaging to detect hot spots.	1	**Rendah**	-
3	Bearing	Cracked	3	3	**Menengah**	Regular bearing inspection and replacement, Quarterly bearing inspection, replace bearings as necessary.	2	**Rendah-Menengah**	-
		Containinated	1	2	**Rendah**	Contamination control and lubrication maintenance, Monthly inspection and lubrication, immediate replacement of contaminated bearings.	1	**Rendah**	-
		Fractured	2	3	**Rendah-Menengah**	Implement sealing solutions and regular inspection, weekly visual inspection, immediate corrective action on detected leakage	2	**Rendah-Menengah**	-

						action on detected leakage.			
4	Shaft Seal Cover	Corroded	2	1	Rendah	Regular inspection and replacement of corroded seals. Monthly visual inspection; replace seals as necessary.	1	Rendah	-
		Fractured	2	1	Rendah	Enhanced environmental protection measures and regular seal inspection. Monthly visual inspection; immediate action on detected hazards. Fluid Leakage:	1	Rendah	-
		Worn	2	1	Rendah	Regular seal maintenance and replacement of worn components. Monthly visual inspection; replace seals as necessary.	1	Rendah	-
5	Shaft	Corroded	3	1	Rendah-Menengah	Regular shaft inspection and anti-corrosion treatment. Monthly visual inspection; annual ultrasonic testing for internal corrosion.	1	Rendah-Menengah	-
		Fractured	2	2	Rendah-Menengah	Immediate replacement of fractured shafts and enhanced monitoring. Bi-weekly visual inspection; immediate action on detected	1	Rendah	-

						immediate action on detected fractures.			
		Worn	2	1	**Rendah**	Regular shaft maintenance and lubrication. Monthly visual inspection and lubrication; replace worn shafts as necessary.	1	**Rendah**	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Corroded	1.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.	no	STOP	STOP	yes	Condition Monitoring	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		1.2 Age and Wear: Like any other equipment on a ship, Cooling pumps and their casings are subject to wear and tear over time. With age, the protective coatings on the casing may degrade, making it more susceptible to corrosion	no	STOP	STOP	yes	Condition Monitoring	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
2	Fractured	2.1 Mechanical Stress: The casing may experience mechanical stress due to factors such as vibration, shock loads, or impacts during normal operation or in rough sea conditions. Over time, this stress can lead to fatigue and eventually fracture of the casing.	no	STOP	STOP	yes	**Condition Monitoring**	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		2.2 Overloading: If the Cooling pump is subjected to loads beyond its design capacity, such as excessive pressure or flow rate, it can put undue stress on the casing, leading to fracture.	no	STOP	STOP	yes	**Condition Monitoring**	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
3	Deformed	3.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	no	**NID**	STOP	STOP	STOP	STOP
		3.2 Corrosion: Continuous exposure to seawater and other corrosive substances can lead to the corrosion of metal casings over time. Corrosion weakens the structural integrity of the casing, making it susceptible to deformation.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	no	**NID**	STOP	STOP	STOP	STOP

4	Corroded	4.1 High Temperatures: Elevated temperatures in the Cooling area, either due to the pump's operation or nearby machinery, can accelerate corrosion processes, especially if combined with other factors like saltwater exposure or chemical contamination.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		4.2 Saltwater Exposure: Ships operate in a highly corrosive environment due to constant exposure to saltwater. If the Cooling pump is not adequately protected or made from corrosion-resistant materials, saltwater exposure can lead to corrosion of the impeller over time.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
5	Fractured	5.1 Material Fatigue: Continuous operation of the Cooling pump impeller can subject it to repeated cycles of stress, leading to material fatigue over time. This fatigue can weaken the material structure of the impeller, eventually resulting in cracks or fractures.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	hid	yes	failure finding	STOP
		5.2 Impact or Mechanical Damage: External factors such as collisions, debris ingestion, or abrasive wear can cause physical damage to the impeller, resulting in cracks or fractures. Impact from foreign objects or sudden changes in operating conditions can lead to immediate failure or accelerate existing damage.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	no	NID	EVD	yes	failure finding	STOP
6	Deformed	6.1 Mechanical Stress: Continuous operation of the Cooling pump can subject the impeller to mechanical stress, especially if it encounters high fluid flow rates or pressure. Over time, this stress can cause the impeller to deform, particularly in areas where the material is weaker or subjected to uneven loading.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

		6.2 Overloading: Excessive loads on the Cooling pump system, such as sudden surges in fluid volume or pressure, can exceed the impeller's design limits and cause deformation. This can occur due to factors like blockages in the pump, changes in fluid viscosity, or improper pump operation.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	YES	**Plan Maintenance**	STOP	STOP	STOP	STOP
7	Cracked	7.1 Impact or Mechanical Damage: External factors like impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the bearings, resulting in cracks.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		7.2 Fatigue: Over time, repeated stress cycles experienced by the bearings during pump operation can weaken the material, leading to microscopic cracks that propagate and eventually result in visible cracks.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	NO	NID	STOP	STOP	STOP	STOP
8	Contaiminated	8.1 Ingress of Foreign Particles: Small particles such as dirt, sand, debris, or rust can enter the bearing housing, especially if the pump is operating in a harsh environment or if seals are compromised. These particles can contaminate the lubricant and cause abrasive wear on the bearing surfaces.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		8.2 Oil or Fuel Leakage: Leakage of oil or fuel from nearby machinery or systems can contaminate the bearing. Oil or fuel contamination can degrade the lubricant's effectiveness, leading to increased friction and wear on the bearing surfaces.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
	Fractured	9.1 .Overloading: Excessive loads on the bearing beyond its designed capacity can lead to fractures. This can happen due to sudden surges in pump operation, such as during startup or when pumping against high resistance, causing stress concentrations and eventual fracture.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP

9		9.2 Fatigue: Prolonged cyclic loading and unloading of the bearing during normal pump operation can lead to fatigue failure over time. This is particularly common in bearings subjected to repeated stress cycles, causing microscopic cracks to form and propagate until complete fracture occurs.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
10	Corroded	10.1 Exposure to Corrosive Substances: The seal may come into contact with corrosive substances present in the Cooling water, such as saltwater, chemicals, or pollutants. Prolonged exposure to these corrosive agents can degrade the seal material and lead to corrosion.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		10.2 High Temperatures and Pressure: Elevated temperatures and pressures within the Cooling pump system can accelerate corrosion processes, particularly if the seal material is not resistant to these conditions.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
11	Fractured	11.1 Material Fatigue: Over time, repeated stress cycles can weaken the seal material, leading to microscopic cracks that propagate and eventually result in a fracture. This fatigue can occur due to the cyclical pressure changes experienced during pump operation.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		11.2 Impact or Mechanical Damage: External factors such as impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the seal, resulting in fractures.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	EVD	YES	failure finding	STOP
		12.1 Abrasion: Continuous contact between the seal and rotating shaft can lead to abrasive wear over time. Particles present in the Cooling water, such as sand, sediment, or debris, can cause abrasive damage to the seal surface, leading to wear	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

12	Worn	12.2 Corrosion: Exposure to corrosive substances in the Cooling water, such as saltwater or chemicals, can corrode the seal material, leading to localized material degradation and wear. Corrosion weakens the seal's structural integrity and can accelerate wear, particularly in areas with high stress concentrations.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
13	Corroded	13.1 Improper Material Selection: Choosing materials for the shaft that are not resistant to corrosion or incompatible with the Cooling environment can promote corrosion and accelerate its progression.	no	STOP	STOP	no	NID	wi	STOP	STOP	no	NID	HID	YES	failure finding	STOP
		13.2 High Humidity and Temperature: Elevated humidity levels and fluctuating temperatures in the Cooling area can create conducive conditions for corrosion to occur on the shaft surface.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
14	Fractured	14.1 Fatigue: Prolonged cyclic loading and unloading of the shaft during pump operation can lead to fatigue failure, causing microscopic cracks to form and propagate over time until a fracture occurs.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		14.2 Corrosion: Corrosive substances present in the Cooling water can degrade the shaft material, reducing its structural integrity and making it more susceptible to fracture failure.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
15	Worn	15.1 Abrasion: Continuous contact with abrasive particles present in the Cooling water, such as sand, sediment, or debris, can gradually wear down the surface of the shaft. This abrasion occurs over time and can lead to the thinning of the shaft diameter or the formation of grooves and pits on its surface.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		15.2Corrosion: Exposure to corrosive substances present in the Cooling water, such as saltwater or chemicals, can corrode the shaft material, leading to localized wear and pitting. Corrosion-induced wear weakens the shaft's structural integrity and accelerates its deterioration.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
perform detailed visual inspections of the pump casing and make temporary repairs to any detected flaws using onboard materials.	CM	3.1 3.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Regular maintenance inspection When flaws are detected	-	Follow recommended inspection procedures carefully to detect any damage
assess the impeller for corrosion damage and, if necessary, replace it with a spare corrosion-resistant impeller available onboard.	CM/PM	4.1 4.2	**Rendah-Menengah**	**Rendah-Menengah**	1500 hours and/or Performed on: Regular maintenance inspection When corrosion damage is detected	-	Conducted by a technician with special attention to corrosion damage
immediately replace the fractured impeller with a spare one and check for any additional damage to the pump system.	FF	5.1 5.2	**Rendah-Menengah**	**Rendah-Menengah**	When damage occurs Performed on: Detection of impeller fracture	-	Replace the fractured impeller promptly and conduct a thorough check for any additional damage.

swap out the deformed impeller with a spare and monitor the pump's performance to ensure the issue is resolved.	CM/PM	6.1 6.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of impeller deformation	-	Replace the deformed impeller with a spare and continuously monitor the pump's performance to confirm that the issue has been effectively resolved.
use onboard ultrasonic equipment to detect any structural weaknesses and apply reinforcements as necessary.	CM	7.1 7.2	**Menengah**	**Rendah-Menengah**	2000 hours and/or Performed on: Regular ultrasonic inspection When structural weaknesses are suspected	-	Follow procedures
inspect seals for wear and replace any compromised seals to prevent fluid leakage using onboard spares.	PM	9.1 9.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours and/or Performed on: Routine seal inspection When wear is detected	-	Conduct a thorough inspection
shut down the pump, replace the fractured seal with an onboard spare, and inspect surrounding components for any additional damage.	FF	11.1 11.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of seal fracture	-	Shutdown the pump to replace the fractured seal

replace the worn seals with spares and apply appropriate lubrication to ensure smooth operation.	PM	12.1 12.2	**Rendah**	**Rendah**	500 hours and/or Performed on: Routine maintenance inspection When wear is detected	-	Replace worn seals with spares

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-CIP-01
System:	Diesel Engine	**Equipment Name:**	Ciculating Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
inspect the cooling pump casings for any signs of corrosion and apply corrosion-resistant coatings as needed.	CM	1.1 1.2	Rendah	Rendah	1000 hours and/or Performed on: Regular maintenance inspection When signs of corrosion are detected	-	Conducted by experienced technicians
check for any fractures in the casing and reinforce the affected areas with temporary clamps or patches to prevent further damage.	CM	2.1 2.2	Rendah-Menengah	Rendah-Menengah	500 hours and/or Performed on: Routine visual inspection When fractures are detected	-	Immediate repairs should be made using appropriate materials to prevent further damage.
apply surface treatments or protective coatings to worn areas of the pump casing using available onboard materials.	PM	8.1 8.2	Rendah	Rendah	1000 hours and/or Performed on: Regular maintenance inspection When wear is detected	-	Use available onboard materials

replace the corroded seal with a new one from the onboard inventory and apply protective coatings to prevent future corrosion.	FF	10.1 10.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of seal corrosion	-	Replace the corroded seal with a new one
replace the corroded component with a corrosion-resistant alternative from onboard spares and apply protective coatings to adjacent parts.	FF	13.1 13.2	**Rendah-Menengah**	**Rendah-Menengah**	When damage occurs Performed on: Detection of component corrosion	-	Replace the corroded component
replace the fractured shaft with a spare if available, and inspect other components for any signs of damage.	FF	14.1 14.2	**Rendah-Menengah**	**Rendah**	When damage occurs Performed on: Detection of shaft fracture	-	Replace the fractured shaft
replace the worn shaft with a new one from the onboard inventory and clean surrounding components to ensure no additional wear or damage.	PM	15.1 15.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of shaft wear	-	Replace the worn shaft with a new one from the onboard inventory

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Circulate coolant fluid to engine and maintaining optimal temperatures for engine operation, within specification Capacity 100 M3/H, Head 20m.	Primary	1.1	No pumping water to initiate coolant circulation (Total Failure)
			1.2	Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	Pump Casing	Corroded	**1.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.**	Random	1. . Reduced Structural Integrity 2. Decreased Pump Efficiency	1.2Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			1.2 Age and Wear: Like any other equipment on a ship, Cooling pumps and their casings are subject to wear and tear over time. With age, the protective coatings on the casing may degrade, making it more susceptible to corrosion	Wear-out		
		Fractured	**2.1 Mechanical Stress: The casing may experience mechanical stress due to factors such as vibration, shock loads, or impacts during normal operation or in rough sea conditions. Over time, this stress can lead to fatigue and eventually fracture of the casing.**	Random	1. Reduced Pump Efficiency 2. Immediate Loss of Functionality	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			2.2 Overloading: If the Cooling pump is subjected to loads beyond its design capacity, such as excessive pressure or flow rate, it can put undue stress on the casing, leading to fracture.	Random		
			3.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can	Random		1.2 Pumping water to suboptimal

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
		Deformed	**cause deformation, especially if the casing material is not sufficiently robust.**		1. Reduced Pump Efficiency 2. Pump Operation with Vibration and Noise	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			3.2 Corrosion: Continuous exposure to seawater and other corrosive substances can lead to the corrosion of metal casings over time. Corrosion weakens the structural integrity of the casing, making it susceptible to deformation.	Wear-out		
2	Impeller	Corroded	**4.1 High Temperatures: Elevated temperatures in the Cooling area, either due to the pump's operation or nearby machinery, can accelerate corrosion processes, especially if combined with other factors like saltwater exposure or chemical contamination.**	Wear-out	1. Reduced Efficiency 2. Material Weakening	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			4.2 Saltwater Exposure: Ships operate in a highly corrosive environment due to constant exposure to saltwater. If the Cooling pump is not adequately protected or made from corrosion-resistant materials, saltwater exposure can lead to corrosion of the impeller over time.	Wear-out		
		Fractured	**5.1 Material Fatigue: Continuous operation of the Cooling pump impeller can subject it to repeated cycles of stress, leading to material fatigue over time. This fatigue can weaken the material structure of the impeller, eventually resulting in cracks or fractures.**	Wear-out	1. Reduced Pump Efficiency 2.. Immediate Loss of Functionality	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			5.2 Impact or Mechanical Damage: External factors such as collisions, debris ingestion, or abrasive wear can cause physical damage to the impeller, resulting in cracks or fractures. Impact from foreign objects or sudden changes in operating conditions can lead to immediate failure or accelerate	Random		
			6.1 Mechanical Stress: Continuous operation			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
	-	Deformed	**of the Cooling pump can subject the impeller to mechanical stress, especially if it encounters high fluid flow rates or pressure. Over time, this stress can cause the impeller to deform, particularly in areas where the material is weaker or subjected to uneven loading.**	Wear-out	1. Vibration and Noise 2. Reduced Pump Efficiency	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			6.2 Overloading: Excessive loads on the Cooling pump system, such as sudden surges in fluid volume or pressure, can exceed the impeller's design limits and cause deformation. This can occur due to factors like blockages in the pump, changes in fluid viscosity, or improper pump operation.	Random		
3	Bearing	Cracked	**7.1 Impact or Mechanical Damage: External factors like impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the bearings, resulting in cracks.**	Random	1. Increased Operating Temperature 2. Structural Damage	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			7.2 Fatigue: Over time, repeated stress cycles experienced by the bearings during pump operation can weaken the material, leading to microscopic cracks that propagate and eventually result in visible cracks.	Wear-out		
		Containinated	**8.1 Ingress of Foreign Particles: Small particles such as dirt, sand, debris, or rust can enter the bearing housing, especially if the pump is operating in a harsh environment or if seals are compromised. These particles can contaminate the lubricant and cause abrasive wear on the bearing surfaces.**	Random	1. Increased Friction and Wear 2. Reduced Efficiency	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			8.2 Oil or Fuel Leakage: Leakage of oil or fuel from nearby machinery or systems can contaminate the bearing. Oil or fuel contamination can degrade the lubricant's effectiveness, leading to increased friction	Random		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			and wear on the bearing surfaces.			
		Fractured	**9.1 .Overloading: Excessive loads on the bearing beyond its designed capacity can lead to fractures. This can happen due to sudden surges in pump operation, such as during startup or when pumping against high resistance, causing stress concentrations and eventual fracture.**	Random	1. Immediate Loss of Functionality 2. Vibration and Noise	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			9.2 Fatigue: Prolonged cyclic loading and unloading of the bearing during normal pump operation can lead to fatigue failure over time. This is particularly common in bearings subjected to repeated stress cycles, causing microscopic cracks to form and propagate until complete fracture occurs.	Wear-out		
4	Shaft Seal Cover	Corroded	**10.1 Exposure to Corrosive Substances: The seal may come into contact with corrosive substances present in the Cooling water, such as saltwater, chemicals, or pollutants. Prolonged exposure to these corrosive agents can degrade the seal material and lead to corrosion.**	Wear-out	1. Corrosion weakens the structural integrity 2. Reduced Seal Performance	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			10.2 High Temperatures and Pressure: Elevated temperatures and pressures within the Cooling pump system can accelerate corrosion processes, particularly if the seal material is not resistant to these conditions.	Wear-out		
		Fractured	**11.1 Material Fatigue: Over time, repeated stress cycles can weaken the seal material, leading to microscopic cracks that propagate and eventually result in a fracture. This fatigue can occur due to the cyclical pressure changes experienced during pump operation.**	Wear-out	1. fractured seal compromises 2. Reduced Seal Performance	1.1 No Pumping water to initiate coolant circulation (Total Failure) 1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			11.2 Impact or Mechanical Damage: External factors such as impacts from debris or improper handling during maintenance			

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			Improper handling during maintenance procedures can cause mechanical damage to the seal, resulting in fractures.	Random		
		Worn	**12.1 Abrasion: Continuous contact between the seal and rotating shaft can lead to abrasive wear over time. Particles present in the Cooling water, such as sand, sediment, or debris, can cause abrasive damage to the seal surface, leading to wear**	Wear-out	1. Reduced Pump Performance 2.Vibration and Noise	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			12.2 Corrosion: Exposure to corrosive substances in the Cooling water, such as saltwater or chemicals, can corrode the seal material, leading to localized material degradation and wear. Corrosion weakens the seal's structural integrity and can accelerate wear, particularly in areas with high stress	Wear-out		
	Shaft	Corroded	**13.1 Improper Material Selection: Choosing materials for the shaft that are not resistant to corrosion or incompatible with the Cooling environment can promote corrosion and accelerate its progression.**	Wear-in	1. Reduced Strength 2. Impeller Misalignment	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			13.2 High Humidity and Temperature: Elevated humidity levels and fluctuating temperatures in the Cooling area can create conducive conditions for corrosion to occur on the shaft surface.	Wear-out		
5		Fractured	**14.1 Fatigue: Prolonged cyclic loading and unloading of the shaft during pump operation can lead to fatigue failure, causing microscopic cracks to form and propagate over time until a fracture occurs.**	Wear-out	1. Loss of Functionality 2.Immediate Loss of Functionality	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
			14.2 Corrosion: Corrosive substances present in the Cooling water can degrade the shaft material, reducing its structural integrity and making it more susceptible to fracture failure.	Wear-out		capacity less than 100 M3/H (Partial Failure)
		Worn	**15.1 Abrasion: Continuous contact with abrasive particles present in the Cooling water, such as sand, sediment, or debris, can gradually wear down the surface of the shaft. This abrasion occurs over time and can lead to the thinning of the shaft diameter or the formation of grooves and pits on its surface.**	Wear-out	1. Reduced Efficiency 2.Seal Leakage	1.2 Pumping water to suboptimal cooling efficiency and potential overheating of equipment within capacity less than 100 M3/H (Partial Failure)
			15.2Corrosion: Exposure to corrosive substances present in the Cooling water, such as saltwater or chemicals, can corrode the shaft material, leading to localized wear and pitting. Corrosion-induced wear weakens the shaft's structural integrity and accelerates its deterioration.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	Pump Casing	Corroded	**Pump Failure: Progressive corrosion of the pump casing weakens the structural integrity of the casing, eventually leading to catastrophic failure, pump malfunction, or complete breakdown, resulting in system downtime and loss of cooling capacity.**	1	2	2	**Rendah**	1. Leakage from cooling Pump 2. Decrease flow rate from cooling Pump	regular inspections, and use of corrosion-resistant materials are essential.
		Fractured	**Environmental Contamination: Fluid leakage from fractured pump casings can contaminate the surrounding environment, posing environmental hazards and safety risks to onboard personnel and marine ecosystems.**	3	1	1	**Rendah-Menengah**	1. Decrease flow rate from cooling Pump 2. No flow from cooling Pump	conduct regular inspections for signs of stress or damage, and ensure that the pump is operated within its design limits.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
		Deformed	**pump Malfunction: Deformed pump casings disrupt the normal operation of the circulating pump, resulting in reduced coolant circulation, loss of system efficiency, and potential pump failure, leading to cooling system downtime and operational disruptions..**	2	1	2	**Rendah**	1. Bend, crack, casing material 2. Decrease flow rate from cooling pump	conduct regular inspections, enhance material selection for casing construction, optimize operating conditions, improve installation practices, enhance maintenance procedures
2	Impeller	Corroded	**Increased Maintenance Costs: Corrosion-related pump failures necessitate costly repairs or replacements, as well as associated labor and downtime expenses, increasing maintenance costs and disrupting vessel operations.**	3	2	1	**Rendah-Menengah**	1. Decrease cooling pump performance 2. Visible corrosion 3. Increase noise and vibration	Assess the damage and consider replacing it with a corrosion-resistant impeller. Implement regular maintenance and consider applying corrosion-resistant coatings.
		Fractured	**Pump Failure: Fractured pump casings jeopardize the structural integrity of the circulating pump, resulting in pump malfunction, reduced coolant circulation, and eventual pump failure, leading to system downtime and loss of cooling capacity.**	2	3	2	**Rendah-Menengah**	1. Decrease cooling pump performance 2. No flow from cooling Pump	Prioritize the installation of a new, intact impeller and conduct regular inspections to prevent future fractures.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
	-	Deformed	**Increased Risk of heating: Inadequate cooling water removal due to impeller deformation increases the risk of heating in critical areas of the ship. This poses a safety hazard to the crew, passengers, and cargo, potentially compromising the vessel's seaworthiness and stability.**	1	1	2	Rendah	1. Decrease cooling pump performance 2. Noise and vibration	Regular inspections and monitoring can help detect deformities early on, preventing further issues.
	Bearing	Cracked	**Compromise structural integrity and load-bearing capacity, leading to progressive deterioration and eventual catastrophic failure, resulting in pump malfunction and system downtime.**	3	3	2	Menengah	1. Visbile abnormal crack 2. Vibration abnormal	Conduct routine visual and ultrasonic inspections to detect early signs of structural damage or load-bearing capacity compromise.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
3		Containimated	**Prone to premature failure due to accelerated wear, surface damage, and reduced load-bearing capacity, ultimately leading to pump malfunction, system downtime, and potentially catastrophic equipment failure.**	1	2	2	**Rendah**	1. Oil /substance analysis 2. Vibration and noise 3. Decrease efficiency	Apply surface treatments or coatings to reduce wear and protect against surface damage.
		Fractured	**Fluid leakage from fractured bearing can contaminate the surrounding environment, posing environmental hazards and safety risks to onboard personnel and marine ecosystems.**	2	3	1	**Rendah-Menengah**	1. Abnormal noise and vibration 2. Lubricant Leakage 3, Decrease flow rate and pressure	Regularly inspect and maintain seals to prevent fluid leakage from bearings.
	Shaft Seal Cover	Corroded	**Fluid Loss: Corroded shaft seal covers can lead to coolant or lubricant leakage from the pump assembly, resulting in reduced fluid levels, loss of system pressure, and diminished cooling or lubrication performance.**	2	1	1	**Rendah**	1. Decrease pressure and flowrate 2. Water leakage arround the pump	conduct a thorough inspection to assess the extent of corrosion and potential leaks.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
4		Fractured	**environmental Hazard: Fluid leakage from fractured shaft seal covers poses environmental hazards, particularly in marine environments, where leaked fluids may pollute waterways or cause harm to marine life.**	2	1	2	**Rendah**	1. Decrease pressure and flowrate 2. leakage of water	Conduct a thorough inspection of the surrounding components for any damage or wear.
		Worn	**Fluid Leakage: Worn shaft seal covers can contribute to increased fluid leakage from the pump assembly, resulting in loss of coolant or lubricant, reduced system performance, and potential damage to surrounding components due to inadequate lubrication or cooling.**	2	1	1	**Rendah**	1. Leakage of water 2. Reduced flow rate, decreased pressure, increase power consumption	Implement preventive maintenance, monitor seal performance, and apply proper lubrication.

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
5	Shaft	Corroded	**Shaft Failure: Severe corrosion can weaken the shaft to the point of mechanical failure, resulting in pump malfunction, system downtime, and potential damage to other pump components.**	3	1	3	**Rendah-Menengah**	1. Friction and vibration 2. Decrease pump flowrate	Apply protective coatings and establish a preventive maintenance schedule to minimize future corrosion risks.
		Fractured	**Pump Failure: Fractured shafts result in the loss of mechanical integrity and functionality of the circulating pump, leading to system downtime, impaired cooling performance, and disruption of ship operations.**	2	2	1	**Rendah-Menengah**	1. cooling water output may have fractured metal shaft 2. Noise and vibration 3. Decrease pump flowrate 4. No flow form cooling pump	consider repairing or replacing it depending on the severity of the damage. Inspect other components for any additional damage or corrosion.
		Worn	**Reduced Efficiency: Worn shafts diminish the efficiency of the circulating pump, as increased friction and surface roughness lead to higher energy consumption, reduced flow rates, and decreased coolant circulation.**	2	1	2	**Rendah**	1. Abnormal vibration and noise 2. Reduce flow rate cooling pump 3. Temperature abnormal caused by friction	address a worn shaft in a cooling pump, promptly replace it with a new one and inspect surrounding components for wear or damage. Implement preventive maintenance measures and monitor pump performance

FMECA WORKSHEET

Maintenance Task Selection

DIGITAL MARINE OPERATION & MAINTENANCE

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	Pump Casing	Corroded	1	2	Rendah	Regular inspection and maintenance of pump casing. Monthly visual inspection; quarterly ultrasonic testing for corrosion detection.	1	Rendah	-
		Fractured	3	1	Rendah-Menengah	Implement containment measures and regular inspection. Bi-weekly visual inspection of pump casings and immediate action on detected fractures.	1	Rendah-Menengah	-
		Deformed	2	1	Rendah	Regular deformation checks and preventive maintenance. Monthly visual inspection; semi-annual structural integrity assessment.	1	Rendah	-
	Impeller	Corroded	3	2	Rendah-Menengah	Corrosion prevention measures and predictive maintenance. Monthly application of corrosion inhibitors; annual cost-benefit	1	Rendah-Menengah	-

						analysis of maintenance.			
2		Fractured	2	3	**Rendah-Menengah**	Enhanced monitoring and immediate repair upon fracture detection. Bi-weekly inspection; immediate corrective action on detected issues.	2	**Rendah-Menengah**	-
		Deformed	1	1	**Rendah**	Regular impeller inspection and replacement of deformed parts. Monthly visual inspection; annual thermal imaging to detect hot spots.	1	**Rendah**	-
3	Bearing	Cracked	3	3	**Menengah**	Regular bearing inspection and replacement, Quarterly bearing inspection, replace bearings as necessary.	2	**Rendah-Menengah**	-
		Contaiminated	1	2	**Rendah**	Contamination control and lubrication maintenance, Monthly inspection and lubrication, immediate replacement of contaminated bearings.	1	**Rendah**	-
		Fractured	2	3	**Rendah-Menengah**	Implement sealing solutions and regular inspection, weekly visual inspection, immediate corrective action on detected leakage	2	**Rendah-Menengah**	-

						action on detected leakage.			
4	Shaft Seal Cover	Corroded	2	1	**Rendah**	Regular inspection and replacement of corroded seals. Monthly visual inspection; replace seals as necessary.	1	**Rendah**	-
		Fractured	2	1	**Rendah**	Enhanced environmental protection measures and regular seal inspection. Monthly visual inspection; immediate action on detected hazards. Fluid Leakage:	1	**Rendah**	-
		Worn	2	1	**Rendah**	Regular seal maintenance and replacement of worn components. Monthly visual inspection; replace seals as necessary.	1	**Rendah**	-
5	Shaft	Corroded	3	1	**Rendah-Menengah**	Regular shaft inspection and anti-corrosion treatment. Monthly visual inspection; annual ultrasonic testing for internal corrosion.	1	**Rendah-Menengah**	-
		Fractured	2	2	**Rendah-Menengah**	Immediate replacement of fractured shafts and enhanced monitoring. Bi-weekly visual inspection; immediate action on detected	1	**Rendah**	-

						immediate action on detected fractures.			
		Worn	2	1	**Rendah**	Regular shaft maintenance and lubrication. Monthly visual inspection and lubrication; replace worn shafts as necessary.	1	**Rendah**	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Corroded	1.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.	no	STOP	STOP	yes	Condition Monitoring	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		1.2 Age and Wear: Like any other equipment on a ship, Cooling pumps and their casings are subject to wear and tear over time. With age, the protective coatings on the casing may degrade, making it more susceptible to corrosion	no	STOP	STOP	yes	Condition Monitoring	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
2	Fractured	2.1 Mechanical Stress: The casing may experience mechanical stress due to factors such as vibration, shock loads, or impacts during normal operation or in rough sea conditions. Over time, this stress can lead to fatigue and eventually fracture of the casing.	no	STOP	STOP	yes	**Condition Monitoring**	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		2.2 Overloading: If the Cooling pump is subjected to loads beyond its design capacity, such as excessive pressure or flow rate, it can put undue stress on the casing, leading to fracture.	no	STOP	STOP	yes	**Condition Monitoring**	STOP	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
3	Deformed	3.1Mechanical Stress: Operating conditions such as vibration, pressure changes, and mechanical shocks can subject the casing to mechanical stress. Over time, this stress can cause deformation, especially if the casing material is not sufficiently robust.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	no	**NID**	STOP	STOP	STOP	STOP
		3.2 Corrosion: Continuous exposure to seawater and other corrosive substances can lead to the corrosion of metal casings over time. Corrosion weakens the structural integrity of the casing, making it susceptible to deformation.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	no	**NID**	STOP	STOP	STOP	STOP

4	Corroded	4.1 High Temperatures: Elevated temperatures in the Cooling area, either due to the pump's operation or nearby machinery, can accelerate corrosion processes, especially if combined with other factors like saltwater exposure or chemical contamination.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		4.2 Saltwater Exposure: Ships operate in a highly corrosive environment due to constant exposure to saltwater. If the Cooling pump is not adequately protected or made from corrosion-resistant materials, saltwater exposure can lead to corrosion of the impeller over time.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
5	Fractured	5.1 Material Fatigue: Continuous operation of the Cooling pump impeller can subject it to repeated cycles of stress, leading to material fatigue over time. This fatigue can weaken the material structure of the impeller, eventually resulting in cracks or fractures.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	hid	yes	failure finding	STOP
		5.2 Impact or Mechanical Damage: External factors such as collisions, debris ingestion, or abrasive wear can cause physical damage to the impeller, resulting in cracks or fractures. Impact from foreign objects or sudden changes in operating conditions can lead to immediate failure or accelerate existing damage.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	no	NID	EVD	yes	failure finding	STOP
6	Deformed	6.1 Mechanical Stress: Continuous operation of the Cooling pump can subject the impeller to mechanical stress, especially if it encounters high fluid flow rates or pressure. Over time, this stress can cause the impeller to deform, particularly in areas where the material is weaker or subjected to uneven loading.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

		6.2 Overloading: Excessive loads on the Cooling pump system, such as sudden surges in fluid volume or pressure, can exceed the impeller's design limits and cause deformation. This can occur due to factors like blockages in the pump, changes in fluid viscosity, or improper pump operation.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	YES	**Plan Maintenance**	STOP	STOP	STOP	STOP
7	Cracked	7.1 Impact or Mechanical Damage: External factors like impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the bearings, resulting in cracks.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	no	NID	STOP	STOP	STOP	STOP
		7.2 Fatigue: Over time, repeated stress cycles experienced by the bearings during pump operation can weaken the material, leading to microscopic cracks that propagate and eventually result in visible cracks.	no	STOP	STOP	YES	Condition Monitoring	wo	STOP	STOP	NO	NID	STOP	STOP	STOP	STOP
8	Contaiminated	8.1 Ingress of Foreign Particles: Small particles such as dirt, sand, debris, or rust can enter the bearing housing, especially if the pump is operating in a harsh environment or if seals are compromised. These particles can contaminate the lubricant and cause abrasive wear on the bearing surfaces.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
		8.2 Oil or Fuel Leakage: Leakage of oil or fuel from nearby machinery or systems can contaminate the bearing. Oil or fuel contamination can degrade the lubricant's effectiveness, leading to increased friction and wear on the bearing surfaces.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
	Fractured	9.1 .Overloading: Excessive loads on the bearing beyond its designed capacity can lead to fractures. This can happen due to sudden surges in pump operation, such as during startup or when pumping against high resistance, causing stress concentrations and eventual fracture.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP

9		9.2 Fatigue: Prolonged cyclic loading and unloading of the bearing during normal pump operation can lead to fatigue failure over time. This is particularly common in bearings subjected to repeated stress cycles, causing microscopic cracks to form and propagate until complete fracture occurs.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	YES	Plan Maintenance	STOP	STOP	STOP	STOP
10	Corroded	10.1 Exposure to Corrosive Substances: The seal may come into contact with corrosive substances present in the Cooling water, such as saltwater, chemicals, or pollutants. Prolonged exposure to these corrosive agents can degrade the seal material and lead to corrosion.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		10.2 High Temperatures and Pressure: Elevated temperatures and pressures within the Cooling pump system can accelerate corrosion processes, particularly if the seal material is not resistant to these conditions.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
11	Fractured	11.1 Material Fatigue: Over time, repeated stress cycles can weaken the seal material, leading to microscopic cracks that propagate and eventually result in a fracture. This fatigue can occur due to the cyclical pressure changes experienced during pump operation.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		11.2 Impact or Mechanical Damage: External factors such as impacts from debris or improper handling during maintenance procedures can cause mechanical damage to the seal, resulting in fractures.	no	STOP	STOP	no	**NID**	wo	STOP	STOP	NO	NID	EVD	YES	failure finding	STOP
		12.1 Abrasion: Continuous contact between the seal and rotating shaft can lead to abrasive wear over time. Particles present in the Cooling water, such as sand, sediment, or debris, can cause abrasive damage to the seal surface, leading to wear	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

12	Worn	12.2 Corrosion: Exposure to corrosive substances in the Cooling water, such as saltwater or chemicals, can corrode the seal material, leading to localized material degradation and wear. Corrosion weakens the seal's structural integrity and can accelerate wear, particularly in areas with high stress concentrations.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
13	Corroded	13.1 Improper Material Selection: Choosing materials for the shaft that are not resistant to corrosion or incompatible with the Cooling environment can promote corrosion and accelerate its progression.	no	STOP	STOP	no	NID	wi	STOP	STOP	no	NID	HID	YES	failure finding	STOP
		13.2 High Humidity and Temperature: Elevated humidity levels and fluctuating temperatures in the Cooling area can create conducive conditions for corrosion to occur on the shaft surface.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
14	Fractured	14.1 Fatigue: Prolonged cyclic loading and unloading of the shaft during pump operation can lead to fatigue failure, causing microscopic cracks to form and propagate over time until a fracture occurs.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
		14.2 Corrosion: Corrosive substances present in the Cooling water can degrade the shaft material, reducing its structural integrity and making it more susceptible to fracture failure.	no	STOP	STOP	no	NID	wo	STOP	STOP	NO	NID	HID	YES	failure finding	STOP
15	Worn	15.1 Abrasion: Continuous contact with abrasive particles present in the Cooling water, such as sand, sediment, or debris, can gradually wear down the surface of the shaft. This abrasion occurs over time and can lead to the thinning of the shaft diameter or the formation of grooves and pits on its surface.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		15.2Corrosion: Exposure to corrosive substances present in the Cooling water, such as saltwater or chemicals, can corrode the shaft material, leading to localized wear and pitting. Corrosion-induced wear weakens the shaft's structural integrity and accelerates its deterioration.	no	STOP	STOP	no	NID	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
perform detailed visual inspections of the pump casing and make temporary repairs to any detected flaws using onboard materials.	CM	3.1 3.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Regular maintenance inspection When flaws are detected	-	Follow recommended inspection procedures carefully to detect any damage
assess the impeller for corrosion damage and, if necessary, replace it with a spare corrosion-resistant impeller available onboard.	CM/PM	4.1 4.2	**Rendah-Menengah**	**Rendah-Menengah**	1500 hours and/or Performed on: Regular maintenance inspection When corrosion damage is detected	-	Conducted by a technician with special attention to corrosion damage
immediately replace the fractured impeller with a spare one and check for any additional damage to the pump system.	FF	5.1 5.2	**Rendah-Menengah**	**Rendah-Menengah**	When damage occurs Performed on: Detection of impeller fracture	-	Replace the fractured impeller promptly and conduct a thorough check for any additional damage.

swap out the deformed impeller with a spare and monitor the pump's performance to ensure the issue is resolved.	CM/PM	6.1 6.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of impeller deformation	-	Replace the deformed impeller with a spare and continuously monitor the pump's performance to confirm that the issue has been effectively resolved.
use onboard ultrasonic equipment to detect any structural weaknesses and apply reinforcements as necessary.	CM	7.1 7.2	**Menengah**	**Rendah-Menengah**	2000 hours and/or Performed on: Regular ultrasonic inspection When structural weaknesses are suspected	-	Follow procedures
inspect seals for wear and replace any compromised seals to prevent fluid leakage using onboard spares.	PM	9.1 9.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours and/or Performed on: Routine seal inspection When wear is detected	-	Conduct a thorough inspection
shut down the pump, replace the fractured seal with an onboard spare, and inspect surrounding components for any additional damage.	FF	11.1 11.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of seal fracture	-	Shutdown the pump to replace the fractured seal

replace the worn seals with spares and apply appropriate lubrication to ensure smooth operation.	PM	12.1 12.2	**Rendah**	**Rendah**	500 hours and/or Performed on: Routine maintenance inspection When wear is detected	-	Replace worn seals with spares

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-SP-01
System:	Diesel Engine	**Equipment Name:**	Suction Pump
Subsystem:	Cooling System	**Drawing:**	Cooling System
Sub-Subsystem:	Main Engine Open Loop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
inspect the cooling pump casings for any signs of corrosion and apply corrosion-resistant coatings as needed.	CM	1.1 1.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Regular maintenance inspection When signs of corrosion are detected	-	Conducted by experienced technicians
check for any fractures in the casing and reinforce the affected areas with temporary clamps or patches to prevent further damage.	CM	2.1 2.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours and/or Performed on: Routine visual inspection When fractures are detected	-	Immediate repairs should be made using appropriate materials to prevent further damage.
apply surface treatments or protective coatings to worn areas of the pump casing using available onboard materials.	PM	8.1 8.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Regular maintenance inspection When wear is detected	-	Use available onboard materials

replace the corroded seal with a new one from the onboard inventory and apply protective coatings to prevent future corrosion.	FF	10.1 10.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of seal corrosion		-	Replace the corroded seal with a new one
replace the corroded component with a corrosion-resistant alternative from onboard spares and apply protective coatings to adjacent parts.	FF	13.1 13.2	**Rendah-Menengah**	**Rendah-Menengah**	When damage occurs Performed on: Detection of component corrosion		-	Replace the corroded component
replace the fractured shaft with a spare if available, and inspect other components for any signs of damage.	FF	14.1 14.2	**Rendah-Menengah**	**Rendah**	When damage occurs Performed on: Detection of shaft fracture		-	Replace the fractured shaft
replace the worn shaft with a new one from the onboard inventory and clean surrounding components to ensure no additional wear or damage.	PM	15.1 15.2	**Rendah**	**Rendah**	When damage occurs Performed on: Detection of shaft wear		-	Replace the worn shaft with a new one from the onboard inventory

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-DT-01
System:	Diesel Engine	**Equipment Name:**	Daily Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Ensures a readily available supply of coolant for daily operations, enhancing operational efficiency and simplifying maintenance and refilling.	Primary	1.1	Loss of total settling capacity: The tank can not hold lube oil. (Total Failure)
			1.2	Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-DT-01
System:	Diesel Engine	**Equipment Name:**	Daily Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	.	Leakage	**1.1Mechanical damage or deterioration of tank walls or seals due to age, corrosion, or impact.**	Wear-out	1. Fluid leakage outside the tank 2. Structural rupture or breach	1.1Loss of total settling capacity: The tank can not hold lube oil. (Total Failure) 1.2Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)
			1.2 Excessive internal pressure or fluid dynamics causing rupture of tank walls or seals.	Random		
		Plugged/ chocked inlet	**2.1 Accumulation of debris, sediment, or foreign objects at the inlet port, blocking the flow of fluids into the tank.**	Random	1.Reduced or obstructed fluid flow into the tank 2. Potential damage or deterioration of inlet components	1.2 Leakage decreased capacity to collect
			2.2 Corrosion or degradation of inlet components, such as screens or filters, restricting fluid passage.	Wear-out		
		Corroded	**3.1Accumulation of debris, sediment, or foreign objects at the outlet port, obstructing the flow of fluids out of the tank.**	Random	1. Reduced or obstructed fluid flow out of the tank 2. Potential damage or deterioration of outlet components	1.2 Leakage decreased capacity to collect
			3.2 Corrosion or degradation of outlet components, such as valves or pipes, restricting fluid passage.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-DT-01
System:	Diesel Engine	**Equipment Name:**	Daily Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	.	Leakage	**1. Water Leakage:** **Leakage from the tank adversely affects system performance, potentially leading to water wastage and operational inefficiencies.** **2. Environmental Impact:** **Water leakage may result in environmental contamination and regulatory non-compliance, particularly in marine environments.** **3. Increased Maintenance Costs:** **Addressing leakage issues requires additional maintenance efforts and resources, leading to increased operational costs and downtime.**	1	2	2	**Rendah**	1. sign of moisture leakage 2. Decrease pressure tank 3. damage tanks	Implement regular inspection and maintenance to detect and address potential issues early.
		Plugged/ chocked inlet	**1.Decreased System Efficiency:** **Blockages reduce the efficiency of the cooling water system by impeding the flow of water, leading to reduced heat transfer rates and diminished cooling capacity.** **2. Equipment Damage:** **Increased pressure drop and flow restrictions resulting from blockages can cause damage to downstream equipment or components, such as pumps or heat exchangers.** **3. Operational Downtime:** **Severe blockages may necessitate system shutdowns and downtime for maintenance and cleaning, disrupting vessel operations and potentially affecting productivity.**	3	1	1	**Rendah-Menengah**	1. Irregularities fluid flow 2. Decrease flow rate	Inspection and repair of corroded or degraded inlet parts.
			1. Decreased Structural Strength:						

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
		Corroded	**1. Decreased Structural Strength:** **Corrosion weakens the tank material, increasing the risk of structural failure or leakage.** **2. Increased Maintenance Requirements:** **Corrosion-related damage necessitates more frequent maintenance and repair interventions.** **3. Risk of Leakage:** **Severe corrosion may lead to pinhole leaks or fractures in the tank, causing water leakage and system inefficiency..**	2	1	2	**Rendah**	1. Decrease flow rate after tank 2. Sign of block and corrotion	Implementation of regular maintenance procedures to prevent blockages and ensure proper fluid drainage.

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-DT-01
System:	Diesel Engine	**Equipment Name:**	Daily Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	.	Leakage	1	2	Rendah	Regularly inspect and maintain tank seals and walls to identify and address potential leakage points early.	1	Rendah	-
		Plugged/ chocked inlet	3	1	Rendah-Menengah	Conduct regular inspections and cleaning of inlet and outlet ports to prevent blockages and ensure efficient water flow.	1	Rendah-Menengah	-
		Corroded	2	1	Rendah	Implement regular inspections to detect early signs of corrosion and structural weakening.	1	Rendah	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Leakage	1.1Mechanical damage or deterioration of tank walls or seals due to age, corrosion, or impact.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		1.2 Excessive internal pressure or fluid dynamics causing rupture of tank walls or seals.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
2	Plugged/ chocked inlet	2.1 Accumulation of debris, sediment, or foreign objects at the inlet port, blocking the flow of fluids into the tank.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Corrosion or degradation of inlet components, such as screens or filters, restricting fluid passage.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
3	Corroded	3.1Accumulation of debris, sediment, or foreign objects at the outlet port, obstructing the flow of fluids out of the tank.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		3.2 Corrosion or degradation of outlet components, such as valves or pipes, restricting fluid passage.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-DT-01
System:	Diesel Engine	**Equipment Name:**	Daily Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
remove any debris or foreign objects from the inlet port using appropriate tools, then conduct a thorough inspection for corrosion or damage and repair any degraded parts immediately to restore proper fluid intake.	CM/PM	2.1 2.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours of operation and/or during routine maintenance checks or when there is a noticeable decrease in fluid intake or performance issues.	.	Performed by a mechanic.
clear any debris or foreign objects from the outlet port using suitable tools, perform a detailed inspection for any signs of corrosion or wear and repair or replace any compromised components to ensure proper fluid drainage.	CM/PM	3.1 3.2	**Rendah**	**Rendah**	500 hours of operation and/or during routine maintenance checks or when there are indications of issues with fluid drainage or reduced pump efficiency.	.	Ensure to follow the manufacturer's/vendor's instructions.

SUMMARY OF MAINTENANCE TASK

CATEGORY C

Functional Group:	Propulsion Function Group		**Equipment ID:**	CO-DT-01
System:	Diesel Engine		**Equipment Name:**	Daily Tank
Subsystem:	Cooling System		**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Emergency Generator System			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
Promptly repair or replace damaged tank walls or seals upon detection of leakage or signs of rupture, ensuring all compromised components are thoroughly inspected and properly sealed to restore full structural integrity	CM/PM	1.1 1.2	Rendah	Rendah	1000 hours and/or Performed on: Conduct regular inspections to detect any signs of leakage or damage to tank walls or seals.	.	Prompt repairs if any issues are identified.

FMECA WORKSHEET

Function and Functional Failure

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-EXT-01
System:	Diesel Engine	**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System		

No (1)	Function Statement (2)	Function Type (3)	No (4)	Functional Failure Statement (5)
1	Accommodates the thermal expansion of coolant, preventing excessive pressure buildup and reducing the risk of leaks or damage.	Primary	1.1	Loss of total settling capacity: The tank can not hold lube oil. (Total Failure)
			1.2	Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)

FMECA WORKSHEET

Bottom-up FMECA

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-EXT-01
System:	Diesel Engine	**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System		

No (1)	Part (2)	Failure Mode (3)	Causes (4)	Failure Characteristic	Local Effect (6)	Functional Failure (7)
1	.	Leakage	**1.1Mechanical damage or deterioration of tank walls or seals due to age, corrosion, or impact.**	Wear-out	1. Fluid leakage outside the tank 2. Structural rupture or breach	1.1Loss of total settling capacity: The tank can not hold lube oil. (Total Failure) 1.2Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)
			1.2 Excessive internal pressure or fluid dynamics causing rupture of tank walls or seals.	Random		
		Plugged/ chocked inlet	**2.1 Accumulation of debris, sediment, or foreign objects at the inlet port, blocking the flow of fluids into the tank.**	Random	1.Reduced or obstructed fluid flow into the tank 2. Potential damage or deterioration of inlet components	1.2 Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)
			2.2 Corrosion or degradation of inlet components, such as screens or filters, restricting fluid passage.	Wear-out		
		Corroded	**3.1Accumulation of debris, sediment, or foreign objects at the outlet port, obstructing the flow of fluids out of the tank.**	Random	1. Reduced or obstructed fluid flow out of the tank 2. Potential damage or deterioration of outlet components	1.2 Loss of settling capacity: The tank can not hold the required amount of lube oil. (Partial Failure)
			3.2 Corrosion or degradation of outlet components, such as valves or pipes, restricting fluid passage.	Wear-out		

FMECA WORKSHEET

Bottom-up FMECA (Lanjutan)

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-EXT-01
System:	Diesel Engine	**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System		

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
1	.	Leakage	**1. Water Leakage:** **Leakage from the tank adversely affects system performance, potentially leading to water wastage and operational inefficiencies.** **2. Environmental Impact:** **Water leakage may result in environmental contamination and regulatory non-compliance, particularly in marine environments.** **3. Increased Maintenance Costs:** **Addressing leakage issues requires additional maintenance efforts and resources, leading to increased operational costs and downtime.**	1	2	2	**Rendah**	1. sign of moisture leakage 2. Decrease pressure tank 3. damage tanks	Implement regular inspection and maintenance to detect and address potential issues early. Conduct pressure tests periodically to ensure structural integrity.
		Plugged/ chocked inlet	**1.Decreased System Efficiency:** **Blockages reduce the efficiency of the cooling water system by impeding the flow of water, leading to reduced heat transfer rates and diminished cooling capacity.** **2. Equipment Damage:** **Increased pressure drop and flow restrictions resulting from blockages can cause damage to downstream equipment or components, such as pumps or heat exchangers.** **3. Operational Downtime:** **Severe blockages may necessitate system shutdowns and downtime for maintenance and cleaning, disrupting vessel operations and potentially affecting productivity.**	3	1	1	**Rendah-Menengah**	1. Irregularities fluid flow 2. Decrease flow rate	Inspection and repair of corroded or degraded inlet parts. Implementation of regular maintenance procedures to prevent blockages and ensure uninterrupted fluid intake.
			1. Decreased Structural Strength:						

No (1)	Part (2)	Failure Mode (3)	End Effect (8)	CoF (9)	Rec PoF (10)	PoF Oreda	Current Risk (11)	Failure Detection/Corrective Measures (12)	Proposed Basic MNTC (13)
		Corroded	**1. Decreased Structural Strength: Corrosion weakens the tank material, increasing the risk of structural failure or leakage. 2. Increased Maintenance Requirements: Corrosion-related damage necessitates more frequent maintenance and repair interventions. 3. Risk of Leakage: Severe corrosion may lead to pinhole leaks or fractures in the tank, causing water leakage and system inefficiency..**	2	1	2	**Rendah**	1. Decrease flow rate after tank 2. Sign of block and corrotion	Inspection and repair of corroded or degraded outlet parts. Implementation of regular maintenance procedures to prevent blockages and ensure proper fluid drainage.

FMECA WORKSHEET

Maintenance Task Selection

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-EXT-01
System:	Diesel Engine	**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System		

No (1)	Part (2)	Failure Mode (3)	Risk Characterization (4)			Task Selection (5)			
			CoF	Rec PoF	Current Risk	Proposed Action(s)	Proj PoF	Proj Risk	Disposisiton
1	.	Leakage	1	2	Rendah	Regularly inspect and maintain tank seals and walls to identify and address potential leakage points early.	1	Rendah	-
		Plugged/ chocked inlet	3	1	Rendah-Menengah	Conduct regular inspections and cleaning of inlet and outlet ports to prevent blockages and ensure efficient water flow.	1	Rendah-Menengah	-
		Corroded	2	1	Rendah	Implement regular inspections to detect early signs of corrosion and structural weakening.	1	Rendah	-

NO	Failure mode	Cause	Confidence on Current Risk	High or Low risk	A	Condition Monitoring Task	B	Cause characteristic	Wear In	C1	Wear Out	C2	Hidden or Evident	Loss Of Function Type	Failure Finding task	C3
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Leakage	1.1Mechanical damage or deterioration of tank walls or seals due to age, corrosion, or impact.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		1.2 Excessive internal pressure or fluid dynamics causing rupture of tank walls or seals.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
2	Plugged/ chocked inlet	2.1 Accumulation of debris, sediment, or foreign objects at the inlet port, blocking the flow of fluids into the tank.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
		2.2 Corrosion or degradation of inlet components, such as screens or filters, restricting fluid passage.	no	STOP	STOP	yes	**Condition Monitoring**	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP
3	Corroded	3.1Accumulation of debris, sediment, or foreign objects at the outlet port, obstructing the flow of fluids out of the tank.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	**Plan Maintenance**	STOP	STOP	STOP	STOP
		3.2 Corrosion or degradation of outlet components, such as valves or pipes, restricting fluid passage.	no	STOP	STOP	yes	Condition Monitoring	wo	STOP	STOP	yes	Plan Maintenance	STOP	STOP	STOP	STOP

SUMMARY OF MAINTENANCE TASK

CATEGORY A

Functional Group:	Propulsion Function Group	**Equipment ID:**	CO-EXT-01
System:	Diesel Engine	**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System	**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System		

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
remove any debris or foreign objects from the inlet port using appropriate tools, then conduct a thorough inspection for corrosion or damage, and repair any degraded parts immediately to restore proper fluid intake.	CM/PM	2.1 2.2	**Rendah-Menengah**	**Rendah-Menengah**	500 hours of operation and/or during routine maintenance checks or when there is a noticeable decrease in fluid intake or performance issues.	.	Debris or foreign objects in the inlet port can obstruct flow and cause damage to internal components
clear any debris or foreign objects from the outlet port using suitable tools, perform a detailed inspection for any signs of corrosion or wear, and repair or replace any compromised components to ensure proper fluid drainage.	CM/PM	3.1 3.2	**Rendah**	**Rendah**	500 hours of operation and/or during routine maintenance checks or when there are indications of issues with fluid drainage or reduced pump efficiency.	.	Debris or foreign objects can cause blockages or damage to the pump system

SUMMARY OF MAINTENANCE TASK

CATEGORY B

Functional Group:	Propulsion Function Group		**Equipment ID:**	CO-EXT-01
System:	Diesel Engine		**Equipment Name:**	Expansion Tank
Subsystem:	Cooling System		**Drawing:**	Sistem Pendingin
Sub-Subsystem:	Main Engine CloseLoop System			

Task (1)	Task Type (2)	Cause Number (3)	Risk (4)		Frequency (5)	Procedure No. Or Class Reference (5)	Comments (6)
			Current	Projected			
repair or replace damaged tank walls or seals upon detection of leakage or signs of rupture, ensuring all compromised components are thoroughly inspected and properly sealed to restore full structural integrity	CM/PM	1.1 1.2	**Rendah**	**Rendah**	1000 hours and/or Performed on: Conduct regular inspections to detect any signs of leakage or damage to tank walls or seals.	.	repair or replacement helps prevent further leakage, which could lead to operational problems or safety hazards

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Fladdy Samudra Bakti was born April 8 2002 in Sleman. Writer completed upper secondary education at SMA Dian Didakatika. The author then continued his college education at Department of Marine Engineering, Institut Teknologi Sepuluh November, Surabaya. While undergoing college education, The author is active in research team activities.

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