BACHELOR THESIS & COLLOQUIUM – ME 1841038

IMPLEMENTATION RELIABILITY CENTERED MAINTENANCE (RCM) METHOD FOR THE MAIN ENGINE OF TUGBOAT X TO SELECT MAINTENANCE TASK AND SCHEDULE

Madina Nur Pratiwi
NRP. 04211641000017

Supervisor
Ir. Dwi Priyanta, M.SE.
Nurhadi Siswantoro, S.T, M.T.

DOUBLE DEGREE PROGRAM
DEPARTMENT OF MARINE ENGINEERING
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IMPLEMENTASI METODE *RELIABILITY-CENTERED MAINTENANCE* (RCM) DARI MAIN ENGINE PADA TUGBOAT X UNTUK MENENTUKAN TUGAS DAN JADWAL PEMELIHARAAN

Madina Nur Pratiwi
NRP. 04211641000017

Dosen Pembimbing
Ir. Dwi Priyanta, M.SE.
Nurhadi Siswantoro, S.T, M.T.

PROGRAM DOUBLE DEGREE PROGRAM
DEPARTMEN TEKNIK SISTEM PERKAPALAN
FAKULTAS TEKNOLOGI KELAUTAN
INSTITUT TEKNOLOGI SEPULUH NOPEMBER
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2020

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APPROVAL SHEET

IMPLEMENTATION RELIABILITY CENTERED MAINTENANCE (RCM) METHOD FOR THE MAIN ENGINE OF TUGBOAT X TO SELECT MAINTENANCE TASK AND SCHEDULE

BACHELOR THESIS

Submitted to Comply One of the Requirement to Obtain a Bachelor Engineering Degree
on
Laboratory of Marine Operational and Maintenance (MOM)
Bachelor Program Department of Marine Engineering
Faculty of Marine Technology
Institut Teknologi Sepuluh Nopember

Prepared By :
MADINA NUR PRATIWI
NRP. 0421641000017

Approved by Academic Supervisor:

Ir. Dwi Priyanta,M.SE. ( )
NIP. 196807031994021001

Nurhadi Siswantoro,ST.,MT. ( )
NIP. 1992201711049

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Prepared By :
MADINA NUR PRATIWI
NRP. 0421641000017

Approved by
Head of Marine Engineering Department

KEMENTERIAN PENDIDIKAN DAN KEBUDAYAAN INSTITUT TEKNOLOGI SEPULUH NOPEMBER FAKULTAS TEKNOLOGI KELAUTAN DEPARTEMEN TEKNIK SISTEM PERKAPALAN

Beny Cahyono, S.T., M.T., Ph.D
197903192008011008

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DECLARATION OF HONOR

I hereby who signed below declare that:
This bachelor thesis has written and developed independently without any plagiarism act, and confirm consciously that all data, concepts, design, references, and material in this report own by Marine Operation and Maintenance (MOM) in Department of Marine Engineering ITS which are the product of research study and reserve the right to use for further research study and its development.

Name	: Madina Nur Pratiwi
NRP	: 04211641000017
Bachelor Thesis Title	: Implementation Reliability Centered Maintenance (RCM) Method for The Main Engine of Tugboat X to Select Maintenance Task and Schedule

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Surabaya, January 2020

Madina Nur Pratiwi

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ABSTRACT

IMPLEMENTATION RELIABILITY CENTERED MAINTENANCE (RCM) METHOD FOR THE MAIN ENGINE OF TUGBOAT X TO SELECT MAINTENANCE TASK AND SCHEDULE

Name : **Madina Nur Pratiwi**
NRP : **04211641000017**
Department : **Marine Engineering**
Supervisors :
1. **Ir. Dwi Priyanta, M.SE**
2. **Nurhadi Siswantoro, S.T., M.T.**

Abstract

Tugboat is the supporting system that plays an essential role in port. A tugboat used for manoeuvring, primarily pulling or pushing bigger vessel in open seas or river to be able to lean in port. PT.X known as a company has a prominent business field in provides such as tug boat. On the PT.X Annual Report of 2018 reported several cases that caused that related to the reliability of the main engine. The failure occurred on the main engine, affected commission days targeted was not achieved. Reliability-centred Maintenance (RCM) is a maintenance method that focused on elevating the reliability of a component in the system(s). RCM used a risk management principle to determine the maintenance task and schedule appropriately. RCM process implemented using the Guide for Survey Based on Reliability-centred Maintenance (RCM) by the American Burau of Shipping (ABS).

Based on the results of this research, there were 40 tasklist type which is obtained based on the analysis of maintenance task allocation and planning. The total of each maintenance types from each failure mode are 19 task for Preventive Maintenance (PM), 16 task for Condition Monitoring (CM), 4 task for Run to Failure (RTF) and 2 task for Finding Failure (FF). Workpackage for each interval is created from every failure mode for each interval for maintenance/inspection.

Keywords: FMECA, Main Engine, Maintenance Schedule, RCM, Tugboat

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ABSTRAK

IMPLEMENTASI METODE *RELIABILITY-CENTERED MAINTENANCE (RCM)* DARI *MAIN ENGINE* PADA TUGBOAT X UNTUK MENENTUKAN TUGAS DAN JADWAL PEMELIHARAAN

Nama : **Madina Nur Pratiwi**
NRP : **04211641000017**
Jurusan : **Marine Engineering**
Dosen Pembimbing :

1. **Ir. Dwi Priyanta, M.SE**
2. **Nurhadi Siswantoro, S.T., M.T.**

Abstrak

Tugboat adalah sistem pendukung yang memainkan peran penting dalam pelabuhan. Kapal tunda yang digunakan untuk bermanuver, terutama menarik atau mendorong kapal besar di laut lepas atau sungai untuk dapat bersandar di pelabuhan. PT.X dikenal sebagai perusahaan yang memiliki bidang bisnis terkemuka di bidang penyediaan seperti kapal tunda. Pada Laporan Tahunan PT.X tahun 2018 melaporkan beberapa kasus yang menyebabkan terkait dengan keandalan pada main engine. Kegagalan terjadi pada *main engine*, mempengaruhi *commision days* yang ditargetkan tidak tercapai. *Reliability-Centered Maintenance* (RCM) adalah metode perawatan yang berfokus pada peningkatan keandalan komponen dalam sistem. RCM menggunakan prinsip manajemen risiko untuk menentukan tugas dan jadwal perawatan dengan tepat. Proses RCM diimplementasikan menggunakan ABS *Guidence*.

Berdasarkan hasil penelitian ini, ada 40 jenis daftar tugas yang diperoleh berdasarkan analisis alokasi tugas pemeliharaan dan perencanaan. Jumlah tiap jenis pemeliharaan dari setiap mode kegagalan adalah 19 tugas pada *Preventive Maintenance* (PM), 16 tugas pada *Condition Monitoring* (CM), 4 jenis tugas pada *Run-to-Failure* (RTF) dan 2 jenis tugas pada *Failure Finding* (FF). Tugas pemelihaaan untuk setiap interval dibuat dari setiap mode kegagalan untuk setiap interval untuk pemeliharaan / inspeksi.

Kata Kunci*: FMECA, Main Engine, Maintenance Schedule, RCM, Tugboat*

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PREFACE

Praise be to God Almighty, for His blessings, the authors can finish "Bachelor Thesis" of reports in accordance with a predetermined time. The authors hope this report can be useful for readers and writers so that they can understand what considerations are used as a reference in making statements about the final project research and data collecting in a particular shipping company. Not to forget the authors to thank the parties who have helped in completing the preparation of this report so that it can be realized include :

1. Ir. Dwi Priyanta, M.SE., as a supervisor of this Bachelor Thesis that has taken the time to give guidance and direction in every workmanship.
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3. Beloved parents, for prayers and support both morally and materially so that this report is completed properly.
4. Shafira Rosyada who always support me all the time. We may not seem such a good friend to each other, but she always standing by my side when times get hard.
5. Mbak Sekar, Mas Niko, and Pak Paul as a mentor to do such an unofficially supervisor to assist more to collecting the data.
6. Alumnus of ITS who have assisted us in explaining the materials in detail and did some data observations.
7. And friends who have given an explanation when the author has not understood in the work of the assignments given.

The author hopes that by writing of the Bachelor Thesis can be useful and provide information to the reader. Because of the limitations of author, constructive criticisms and suggestions are indispensable for perfection in this report

Surabaya, January 26th 2020

Madina Nur Pratiwi

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CHAPTER 1
BACKGROUND

1.1 Background

Indonesia is one of the largest archipelagoes in the world because it exceeds 17,000 islands. The length of Indonesia's coastline reaches 95,181 km, with a sea area of 5.4 million km2, and the total area of Indonesia's territory is 7.1 million km. The sea is very identical to the resources in it. Several sectors can be developed, such as aquaculture, marine tourism, sea transportation, mineral resources, coastal forests, non-conventional resources, small islands, aquatic product processing industries, and others.

At present, the government is developing one sector, using sea transportation for logistics purposes. The government try to balancing the supply and demand for goods and services, from one region to another. With the encouragement from the government, driving growth in sea transportation.

Supply Chain Indonesia (SCI) analysis five sub-sectors of Indonesia's transportation, those are land transportation, air transportation, sea transportation, river, lake and crossing transportation, and rail transportation. Based on **Figure 1.1**, sea transportation is in the third position, which shows a stable growth rate every year. With the increases in the sea transportation sector, there are needs supporting system for helping the development industry, such as tugboat use.

A tugboat is a ship used for manoeuvering, primarily pulling or pushing other bigger vessels in ports, open seas or rivers. Tugboat has a function in port operations to attract and encourage ships to be able to berth to carry out loading/unloading activities. Tugboats also have a role in the industry, such as the use of barges that require tugboats (Mori, 2016).

Tug and Barge is sea transportation that can carry large amounts of cargo with a size of 300 - 350 ft. A barge is capable of carrying 7000 tons of bulk cargo. This kind of economic value of the tugboats more efficient compared to other types of ships. Because of this, tug and barge dominate Indonesia's shipping lanes, especially coal, sand, iron ore, and other bulk loads (Sri, et al., 2017).

The shipping industry is known to have high potential or risks related to safety. If an accident occurs, it will cause various consequences related to human safety, financial and environmental. Ship accidents consist of collisions, equipment failures, explosions, fires, leaks, aground, overturned, sinking, and others (Sri, et al., 2017).

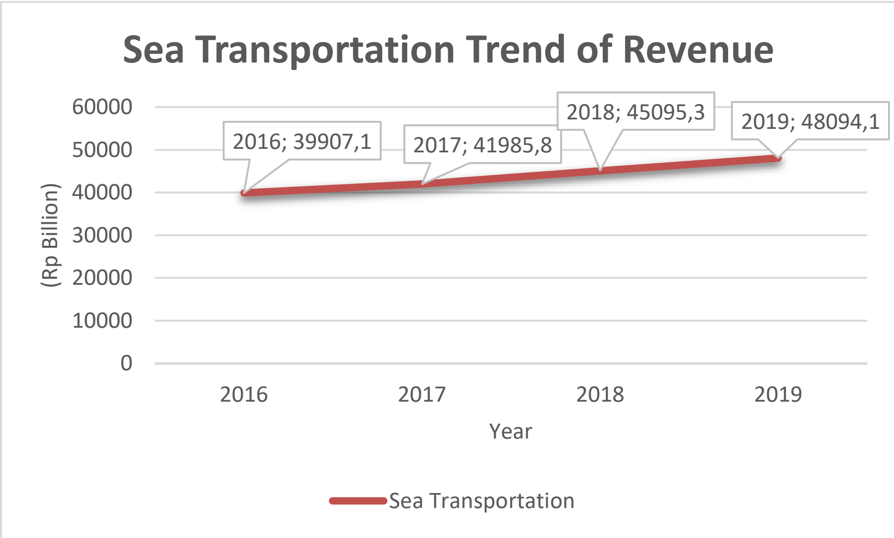

Figure 1. 1 Growth and Prediction of Indonesian Transportation Sector Value in 2016-2019[1]

Based on the analysis of ship accident data, reported by the *Dinas Perhubungan Indonesia* shown in **Figure 1.2**, there are several causes of accidents such as human error, natural factors, and other factors. Among them, human error is the most significant causes of accidents on a ship.

Quoted from the P&I club (Protection and Indemnity insurance) in analysing statistical data found human error factor is a common factor that caused machine operation failures Human error defined as incorrect operation of the machine or maintenance/inspection of the engine.

The statistical data analysed by the P&I club from the total number of 2,000-2,500 accidents annually. **Figure 1.3** shows the number of each cause of accidents such as manoeuvring accidents (red), engine damage (blue), and other accidents (green). This data shows that the percentage of accidents due to engine damage e reaches 15% of the total number of ship accidents per year. Other accidents defined due to hull & structure, irresistible force, mishandling of combustible materials, and mismanagement of storage areas, and others (P&IClub, 2017)

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[1] Setijadi, "*Sektor transportasi diprediksi tumbuh 11,5% pada 2019*" (http://supplychainindonesia.com/new/sektor-transportasi-diprediksi-tumbuh-1115-pada-2019/, Accessed on August 17, 2019).

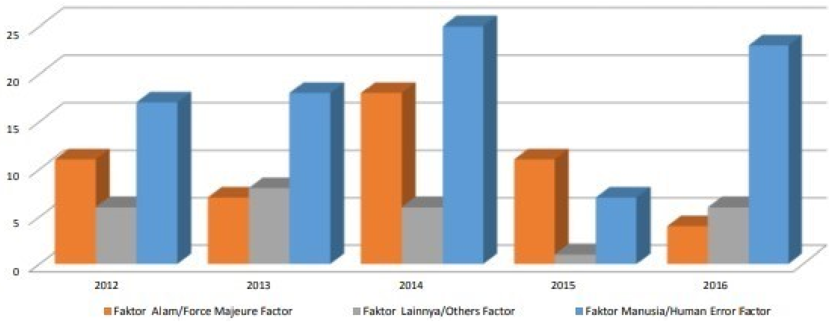

Figure 1. 2 Number of Court Decisions According to Factors Causing Ship Accidents *(Perhubungan, 2016).*

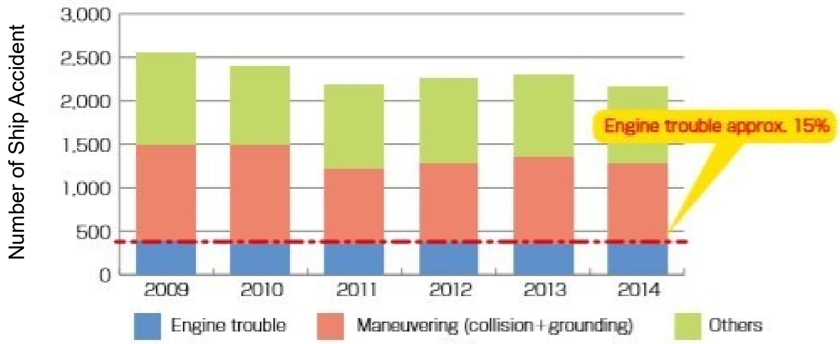

Figure 1. 3 Trend of number of ship accidents *(2009-2014) (P&IClub, 2017)*

P&I club also analysed the "Report of the Japan Maritime Accident Tribunal" from 2009 - 2014. In the analysis, **Figure 1.4** shows the percentage of engine trouble causes due to faulty maintenance, inspection, main engine operation reaching 65%. While other causes such as maintenance errors, inspection and handling of lubricating oil (21%), maintenance errors, inspections, and auxiliary engine operations (10%), lack of maintenance management (1%), and others. (3%) (P&IClub, 2017).

Based on ship accident data with engine problems due to maintenance, which can cause the ship to fail to operate. Ship failure will adversely affect companies that own ship charter. Because it has a low-performance ship or in other words does not have enough availability needed by the user.

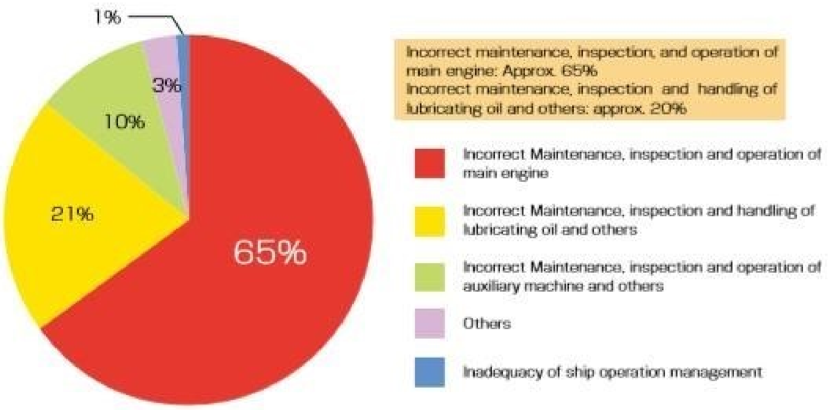

Figure 1. 4 The case of maritime accidents causes (engine trouble) (2009-2014) *(P&IClub, 2017)*

If a ship accident occurs, it can decrease the operational day of a vessel. Then, the targeted commission days that have been agreed by the second party has not reached. When this happens, both parties will incur the losses. The users of the charter ship will face loss costs because business mobility hampered and the shipowner will get a penalty from the user because the ship used does not reach the commission days that targeted. Also, charter vessel owners will lose the trust of the user because they cannot guarantee the quality of the charter ship.

Therefore, to ensure that the tugboat is operating in an optimal condition with implementing appropriate management maintenance. Because efficient management maintenance will turn into optimal system performance, it also maintains the life-time of each component on a system.

1.2 Problem Statements

Based on the background that has described, the problem that can be solved in this Thesis are:

1. How to determine the hierarchy of components based on each function system?
2. How analyse the failure and risk caused by components in the main engine of Tugboat?
3. How to determine the appropriate maintenance task and schedule on the main engine of Tugboat to reduce downtime during the operational period of the Tugboat

1.3 Scope and Limitation

This thesis focused on the limitation on the problem there are:

1. This thesis using Guide for Survey Based on Reliability-centred Maintenance by the American Bureau of Shipping (ABS)
2. The research object is the Main engine of Tugboat owned by PT. X
3. The failure data of components is taken from planned maintenance system within one year

1.4 Objectives

Based on problems, the objectives of this final project are:

1. Identify the hierarchy of components based on each function systems
2. Identify the failure and risk caused by components in the main engine of Tugboat
3. Determine the maintenance task and schedule on the main engine of Tugboat to reduce downtime during the operational period of the Tugboat

1.5 Benefit

The expected benefits of this thesis are as follows:

1. Provide advice to companies in implementing the RCM method for maintenance activities on the main engine of Tugboat
2. As an evaluation of the maintenance system that already applies to the company
3. Provide information regarding the implementation of maintenance activities using the RCM method based on ABS Rules.

1.6 Deliverable

The deliverable of this thesis is the RCM information worksheet (FMECA), Decision Worksheet, and maintenance task and scheduling for the main engine of Tugboat

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CHAPTER 2
STUDY LITERATURE

2.1 Problem Overview

PT. X is a state-owned company which has a business sector engaged in shipping. PT. X has 12 operating locations throughout Indonesia, and those are Medan, Makassar, Jambi, Dumai, Cilacap, Balikpapan, Plaju, Batam, Tanjung Priok, Surabaya, Bontang, and Sorong.

PT. X offers several products and services, namely provider of ships as operational fleets, charters & brokerage, ship agency services, vessel management, port management, shipping fuel for ships or tankers, and others. PT. X ships have various types of vessels, such as tankers, AHTS (Anchor Handling Tug Supply vessel), tugboats, LNG (Liquefied Natural Gas vessels), mooring boats, SPOB (Self Propelled Oil Barge), RIB (Rigid Inflatable Boat), and others (Continental, 2018). **Figure 2.1** shows the number and type of vessels owned by PT. X.

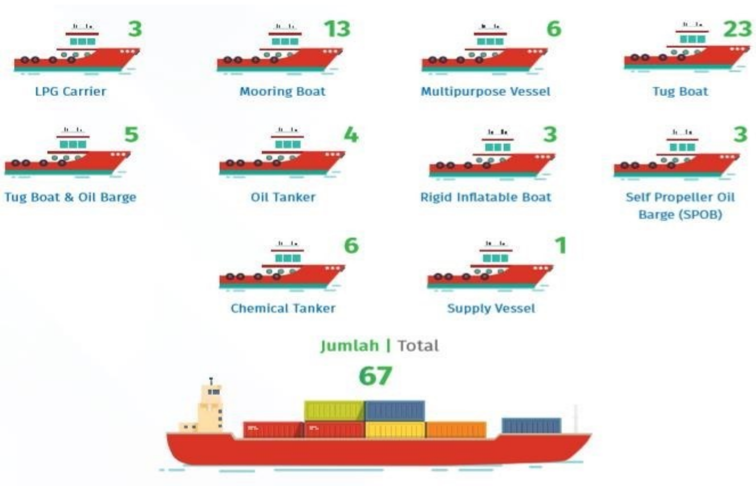

Figure 2. 1 Type of Vessel at PT. X *(PT.X, 2018)*

PT. X has a prominent business field in providers of light vessels, such as tug boats, mooring boats, AHTS, and others. So PT. X has a high demand for the light vessels they provide. Also, PT. X has high mobility to national energy needs.

In the data reported by PT. X, the commission days earned each year experienced a significant increase, as shown in **Figure 2.2**. Especially in 2018, increase to 43.77%. PT. X vessels must have high availability to achieve the commission days that targeted, (PT.X, 2018).

PT. X as a company that has a business on chartered vessels, in 2012, has an effort to maintain the quality of ships by implementing the Planned Maintenance System (PMS) as preventive maintenance. Then, in 2017, PT. X implemented CERTO (Certificate Online) on several owned vessels. CERTO performs maintenance still applying OEM (Original Equipment Manufacturer), per running hours. In the application of PMS, PT. X management has sufficient time discipline, with treatments based on running hours, oil analysis, surveys, and others.

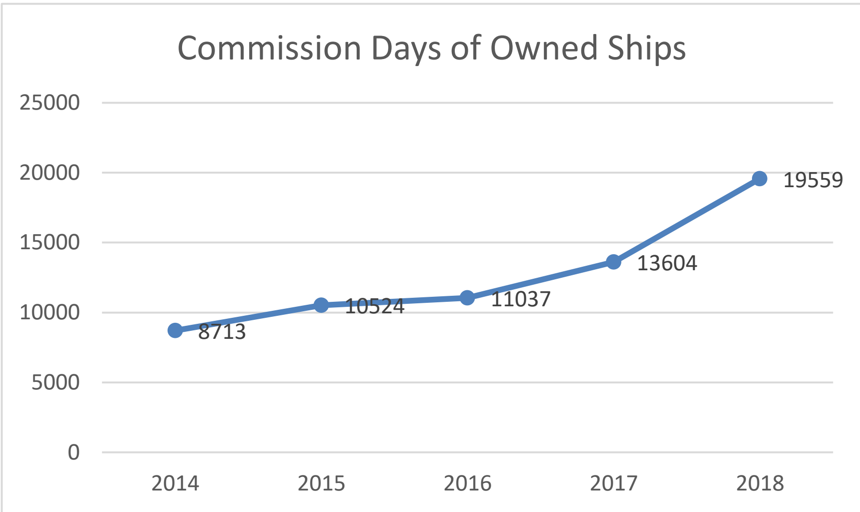

Figure 2. 2 Commission days of ships owned by PT. Pertamina Trans Kontinental *(PT.X, 2018)*

In 2018 the realisation of commission days for ships reached 19,559 days or 43.77% increases compared to 2017, which only reached 13,604 days, shown in **Figure 2.2**. However, despite an increase from the previous year, commission days in 2018 only reached 89.67% from the target of the 21,813 days in the 2018 RKAP (*Recana Kerja dan Anggaran Perusahaan*) (PT.X, 2018).

These ships must have high availability to meet the demand for charters; in other words, the equipment of each ship must have high reliability, such as the main engine because the main engine is the main critical equipment contributor to the availability of ships. One form of prevention for damage is maintenance management.

In the annual report in 2018 also reported the several factors that caused the commission days target were due, which include:

1. Patra Tanker 2 & Transko were still docking from September to October.
2. RIB 4 was effectively off-hire since 25 July 2018 due to excessively large waves causing the ship to sink.
3. Patra Tanker 1 in September 2018 only achieved 26 days due to suction valve repair. In November, it was off-hire on 19 November 2018 at 07:00 due to Main Engine Issue, back on hire on 30 November 2018 at 13:00.
4. Comdays of Transko Aries in October achieved 28 days due to Main Engine trouble and engine trouble of the ship. In November 2018, it was off hired on 24 November 2018 at 13:18 due to engine trouble and back On Hire on 25 November 2018 at 16:00.
5. MT Gas Patra in November 2018 was off hired on 30 November 2018 at 19:30 due to Engine Trouble and back on hire on 01 December 2018 at 22:30.
6. Transko Nuri in 2018 achieved full commission days.
7. Transko Taurus Ship began operations on 11 August 2018. It did not experience any off-hire since the operation began.
8. Tug Boat 4201 on 11 December was off-hire due to cylinder head engine trouble and back on hire on 22 December 2018.

Some of the reported cases are related to the reliability of the main engine that affects commission days targeted at the company. RCM (Reliability Centered Maintenance) is a form of preventive maintenance method that aims to maintain the reliability of a system. RCM defined as structuring, logic processes for developing or optimising maintenance.

Historically, RCM established as a method applied to US Navy ships (Marcin K., 2017). It also reported that RCM is an excellent methodology for analysing RCM maintenance needs because the philosophy of the main points can be easily used to make plans or decisions on maintenance (Raj & Raj, 2014). RCM also was adopted by the Royal Navy (RN) in 1995 that reported cost savings and improvements in availability (New & Gay, 2012).

Applying RCM to marine machinery will bring some benefits such as an integrated program that address to machinery integrity and reliability, increased life of critical components of machinery, cost effective maintenance, and improves understanding of equipment failures and their impact on vessel performance (Conachey & Montgomery, 2002).

Therefore, in this thesis will implementing the RCM method with FMECA analysis (Failure Mode, Effects and Critical Analysis) of ABS Rules on the main engine system of Tugboat owned by PT. X to selecting maintenance task.

2.2 Main Engine System

The marine diesel engine is a very complicated mechanical system. The diesel engine offers various advantages such as high efficiency, high power concentration and long operational lifetime.

The different subsystem of the marine diesel engine are cooling, lubrication, air, and injection, as shown in **Figure 2.3.**

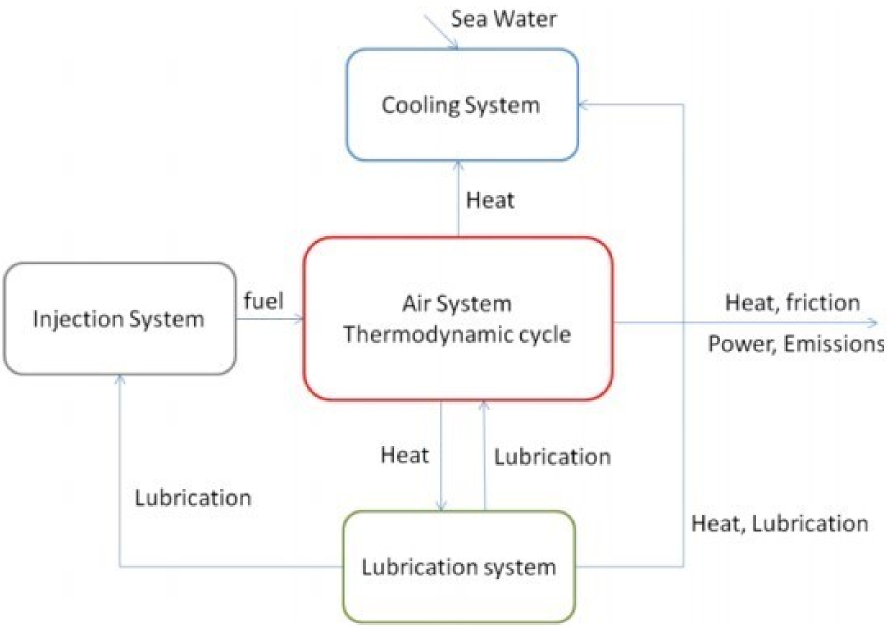

Figure 2. 3 Subsystems of the marine diesel engine *(Nahim, et al., 2015).*

The characteristics of the system summarised below:

1. Cooling System

   Engine cooling system plays an important role to maintain the operating temperature of the engine. The coolant circuit initiates by picking up heat at water jackets. The cooling system consists of two types of circuit, seawater and freshwater circuit. Each circuit is activated with a pump, depending on the temperature of the freshwater, a thermostat controls the flow of water to the heat exchanger when it is hot, or directly to the pump if it is relatively cold. The system cools the oil before its inlet to the engine, and cool the air going to combustion chamber at its outlet from the compressor. The components of the system, shown in **Figure 2.4.**

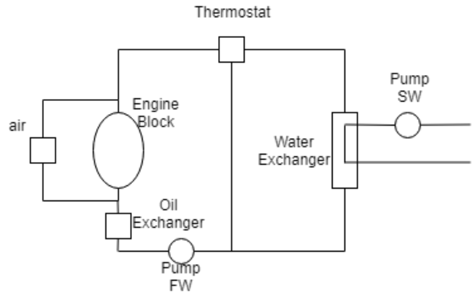

Figure 2. 4 Cooling System Components

2. Lubricating System
   Lubricating systems work to keep the engine clean and free from rust and corrosion. Engine oil is expected to provide a protective film, to prevent metal to metal contact and reduce friction. It must help remove heat from engine surfaces and flush away wear particles. It also aids in sealing the piston rings, serves as a hydraulic fluid. The lubrication circuit of the combustion engine involves many components shown in **Figure 2.5**.

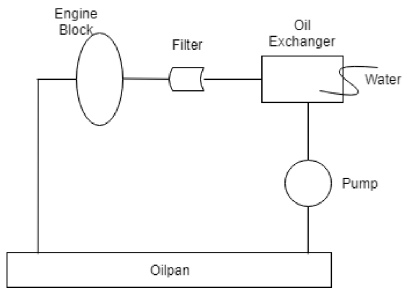

Figure 2. 5 Lubricating System Components

3. Injection System
   The fuel injection system is responsible for supplying the diesel engine with fuel. The injection system drives fuel from the tank to the combustion chamber. The main elements of a common rail diesel

injection system are a low-pressure circuit, including the fuel tank and a low-pressure pump, and a high-pressure pump with a delivery valve. The low-pressure pump sends the fuel coming from the tank to the high-pressure pump. Hence the pump pressure raises, and when it exceeds a given threshold, the delivery valve opens, allowing the fuel to reach the common rail. The common rail hosts an electro-hydraulic valve driven by the electronic control unit (ECU), which drains the amount of fuel necessary to set the fuel pressure to a reference value. The high-pressure pump connected by a small orifice to the low-pressure circuit and by a delivery valve with a conical seat to the high-pressure circuit. When the piston of the pump is at the lower dead centre, the intake orifice is open and allows the fuel to fill the cylinder, while the downstream delivery valve is closed by the forces acting on it. Then, the closure of the intake orifice, due to the camshaft rotation, leads to the compression of the fuel inside the pump chamber. The system is presented in **Figure 2.6.**

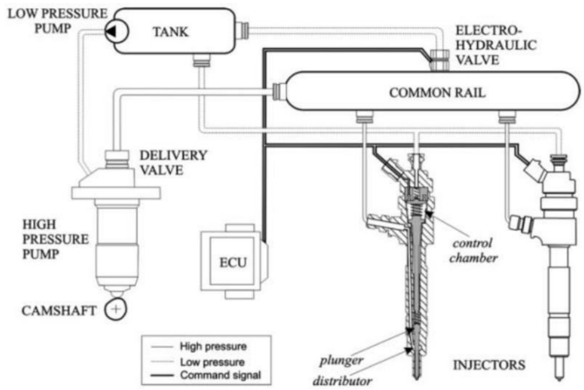

Figure 2. 6 Injection System Components

4. Air System

Compressed air has many uses inboard such as starting engine cleaning and machinery during maintenance in the main engine system. This air system uses a high-pressure system. Air at a pressure of 20 to 30 bar is required for starting the main diesel engine. The compressed air system is shown in **Figure 2.7.**

Usually in Compressed air system has two air compressors and two reservoirs with sufficient capacity. The receivers must store sufficient air for the starts without the need for top-up from the compressors. Safety valves are generally fitted to the air receivers, but in some installations, the reservoirs are protected against overpressure by those of the compressors. There is a requirement that if the safety valves can be isolated from the reservoirs, the latter must have fusible plugs fitted to release the air in the event of fire.

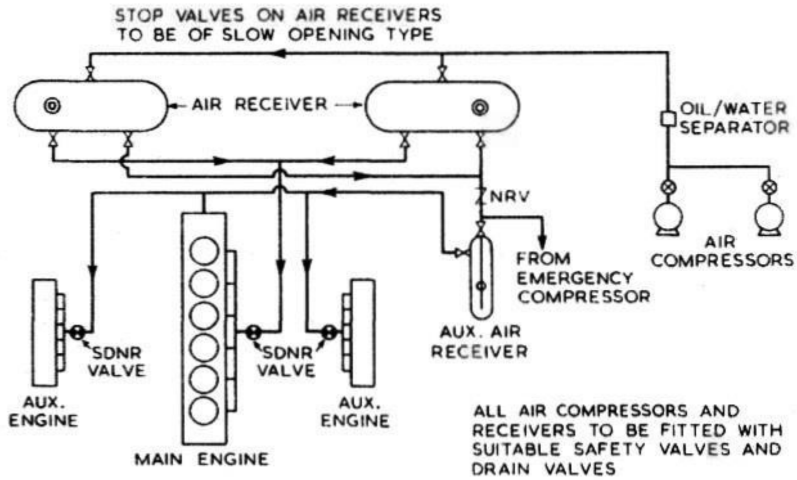

Figure 2. 7 Air System Components

2.3 Maintenance

Maintenance is the concept of all activities needed to maintain the quality of equipment. This activity is intended to ensure that the physical assets owned can continue to fulfil what the user wants. By doing maintenance, it expected that the reliability of a system could increase.

A maintenance activity also requires a planned standard operating. There are two main principles, those are:

1. Break down period is at a minimum point by considering economic aspects
2. Avoiding unplanned break downs and sudden damage.

Therefore, maintenance is long-term strategic planning, which integrates all lifecycle phases; the role of maintenance will make an impact when the system starts to experience disruption or can not operate.

2.4 Evolution of Maintenance

Maintenance strategies have evolved significantly over the past 50 years to allow for several generations of evolution to be distinguished. Since the 1930s, maintenance has divided into four generations. These four generations have changed in methods that increasingly benefit an industry that can maximise the reliability of equipment.

2.4.1 First Generation

Around the 1930s, disruption was not too much of a problem. "fix it when it broke" is the motto of the first generation. Because it has an industry that is not very mechanical. This kind of industries shows that prevention is not a priority. This generation has enough in cleaning routine and lubrication.

2.4.2 Second Generation

In the 1950s, machines of all types were more numerous and complex. Mechanisation has increased. Industries at that time began to have a dependency on mechanisation.

The second generation focused on the breakdown time caused by equipment. The industry also has the idea to prevent failures in equipment that gave birth to the concept of preventive maintenance.

In the 1960s, equipment maintenance was carried out at fixed intervals. Also increases maintenance costs. However, behind the increasing cost of maintenance, the industry has a control system to prevent equipment failures. Also, consequently, the amount of capital has increased sharply, so the industry will try to maximise the lifetime of assets.

The second-generation maintenance concept has the advantage of higher availability, longer lifetime, and has maintenance costs that are not too high.

2.4.3 Third Generation

Entering the 1970s, the process of evolution in the industry is more significant. At this time, automation is a significant issue in the industry. Because automation will provide high-quality standards and high production capabilities as well.

However, the automation system will bring more operational failures. Eventually, the operational failures will have more consequences on the safety and environmental and the amount of dependence on the integrity of physical assets increases. Likewise, with the costs to operate, therefore the industry must work efficiently to balance the company's financial situation.

Finally, maintenance costs are absolute in industry and have the second-highest proportion of total expenditure after production costs. The third-generation concept, has higher availability & reliability, better security, guaranteed product quality, no environmental damage, longer asset life, and is cost-effective (Moubray, 1997).

2.4.4 Fourth Generation

Maintenance over the next few years will be encouraged to utilise technology to obtain efficiency in retrieving data provided by technology. The start of the fourth generation, marked by the strategic thinking of maintenance experts and technology providers, The proliferation of technology offerings we now experience becomes more rationalised into logical sets of efficient, strategic, integrated data-led tools.

The existence of such a system will make the maintenance system more adaptive to changing environmental needs and more flexible to allow it to be statistical[2].

2.5 Maintenance Techniques

In the first generation to the fourth generation has experienced an evolution in the concept and treatment techniques. **Figure 2.8** shows how improvements in the administrative system have become more developed over time.

Several techniques created which show how to manage treatments properly. The third development techniques include, as follows:

- Decision makings, such as Hazard studies, FMEA (Failure Modes and Effects Analysis), and expert systems
- The latest maintenance technique, namely condition monitoring
- Design equipment by maximising reliability and availability
- Changes in organisational thinking to produce flexible and effective teamwork.

[2] Malcolm H., "*Fourth Generation Maintenace*", 2013, pg. 5-7 (https://stratmaint.com/wp-content/uploads/2016/12/Fourth-generation-maintenance-v2.0.pdf Accessed on August 29, 2019).

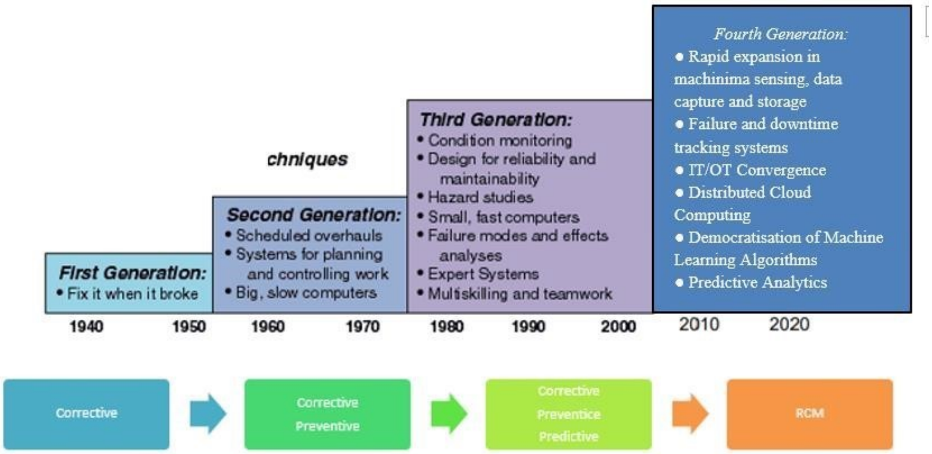

Figure 2. 8 Maintenance Techniques[3] *(Moubray, 1997)*

Maintenance development will continue to develop. Because the methods in the first, second, and third-generation will not last long to give failure to an asset. The fourth-generation has an essential part of finding a better way to collect data and share data, as follows:

- Worst case scenario planning
- Zero-Demand Flexibility Observation Management and Upgrade Preparation
- Business Criticality Alignment
- Performance Monitoring
- Maintenance Reductionism
- Skills-managed maintenance design
- Automated Data-Led Analysis and Solutions
- Adaptive Maintenance Strategies
- Automated Tracking and Reporting
- Statistically-Based Inspection Frequencies[4]

Based on the literature on the fourth generation of maintenance, its likely have more focuses on failure elimination, rather than failure prediction or prevention. The improvement activities will concentrate on reducing the

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[3] Denis Marshment, "*The fourth generation of maintenance*", 2018 (https://www.linkedin.com/pulse/fourth-generation-maintenance-denis-marshment?articleId=6432557646942998528#comments-6432557646942998528&trk=public_profile_article_view Accessed on 29 August 2019).

[4] Malcolm H., "*Fourth Generation Maintenace*", 2013, pg. 5-7 (https://stratmaint.com/wp-content/uploads/2016/12/Fourth-generation-maintenance-v2.0.pdf Accessed on August 29, 2019).

proportion of equipment failures that comply with Nowlan and Heap's Failure Infant Mortality Pattern. It will also focus on reducing the overall levels of failure probability[5].

The challenges that exist in maintenance are not only in these maintenance techniques but also have the right decision on improving asset quality, and it will also affect the maintenance costs of an asset. The wrong decision would make new problems will arise and make things worse (Moubray, 1997).

2.6 Six Failure Pattern

There is six failure pattern that founded in several generations. This six failure patter divided into age-related and non-age related failure.

The age-related pattern defines the pattern that has probability failure rate increases once the equipment has reached a certain age or time-based depending on running hours of the equipment usage. The total of age-related (time-based) failure pattern only accounts for 11% of all age-related failure patterns.

The non-age related pattern highlight the fact during the start-up is when the majority of failure will occur. This could be due to maintenance induced failures, or manufacturing defects in equipment. The initial start-up period failure is random. The total of non-age related failure pattern accounts for 89% of all non-age related failure patterns.

Down below are the explanation of each pattern that shown in **Figure 2.9**, those are:

1. Pattern A is a bathtub curve that starts with a high incidence of failure, followed by a probability of conditional failure, which increases gradually. This pattern accounts for approximately 4% of failures.
2. Pattern B is the wear out curve, that shows the probability of conditional failure that continues to increase along with the age of operational assets. This pattern accounts for approximately 2% of failure.
3. Pattern C is a fatigue curve, that shows the possibility of conditional failure, which increases slowly, but there is no identifiable wear-out age. This pattern accounts for approximately 5% of failure.
4. Pattern D is an initial break-in period curve, that shows a low probability of conditional failure when the item is new or just left the store, then a quick increase to a constant level. This pattern accounts for approximately 7% of failure.

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[5] Sandy Dunn, "*The Fourth Generation of Maintenance*", copyright 1996-2009, The Plant Maintenance Resource Center (http://www.plant-maintenance.com/articles/4th_Generation_Maintenance.pdf Accessed on September 6, 2019)

5. Pattern E is a random curve, that shows the probability of conditional failure being constant at all ages (random failure). This pattern accounts for approximately 14% of failure.
6. Pattern F is an infant mortality curve, which shows a high initial failure rate in starts but eventually goes down to a constant or very slow probability of conditional failure. This pattern accounts for approximately 68% of failure.

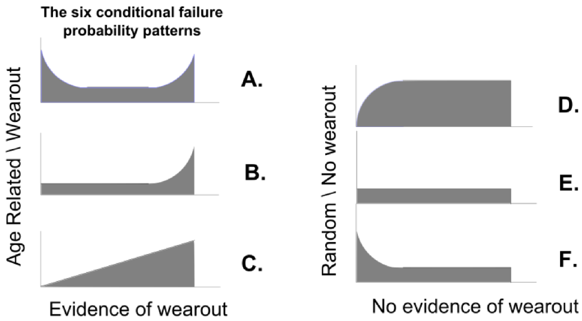

Figure 2. 9 Six Failure Pattern *(Moubray, 1997)*

2.7 Type of Maintenance Strategies

Forms of maintenance classified into two types, namely planned maintenance and unplanned maintenance. However, there are maintenance actions that need to take if there is a severe incident where if not carried out maintenance actions will cause serious consequences such as obstruction of the production process, equipment damage, and safety reasons called emergency maintenance.

As shown in **Figure 2.10**, maintenance can be classified into several types of maintenance, as follows:

1. Preventive Maintenance

   Preventive Maintenance is a type of proactive maintenance to maintain certain service levels on equipment, program their vulnerability interventions in the most appropriate time. How to implement regular preventive maintenance, i.e. equipment is inspected even if it does not provide symptoms of experiencing problems, maintenance tasks are carried out based on time rather than actual conditions. By way of prevention such as this preventive maintenance, experience cost savings of 12% to 18% compared to reactive maintenance.

Advantage:
- Maintain assets and operate longer than other types of maintenance
- The cost of long-term repairs is usually much lower
- Security is improved because it can reduce the chance of failure

Disadvantage:
- More complex than other types of treatments
- Requires more investment early on[6]

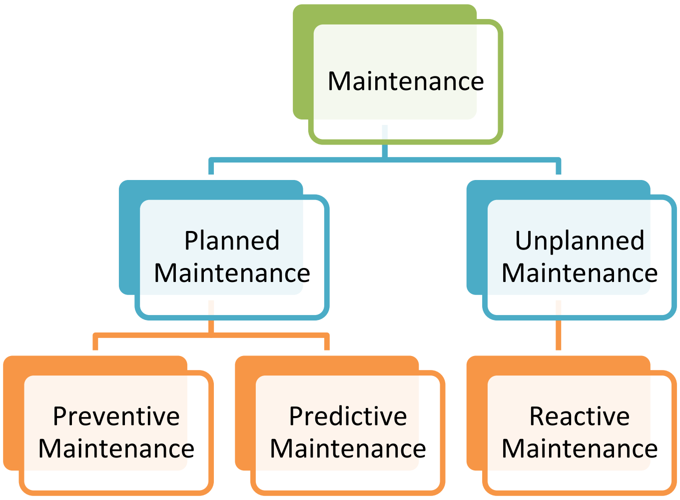

Figure 2. 10 Type of Maintenance

2. Predictive Maintenance

Predictive Maintenance is a voting process known as condition monitoring to check the status of assets regularly. Knowing and reporting the status and operational capacity of the plant by knowing the values of certain variables, which represent the circumstances and operational capabilities. This maintenance is technical, because it requires sophisticated technical resources, and at the time of strong mathematical, physical and technical knowledge. Predictive maintenance provides a cost savings of 8% to 12% of preventive maintenance.

Advantage:
- Keep the costs and downtime are at the minimum cost
- The possibility of failure reduced, and reliability is improved

Disadvantage:

[6] Hansford Sensors, "*The pros and cons of different maintenance strategies*" (https://www.hansfordsensors.com/the-pros-and-cons-of-different-maintenance-strategies/, Accessed on August 26, 2019).

- Requires a long time to implement
- Upfront costs are higher than the basic maintenance strategy[7]

3. Corrective Maintenance

   Corrective Maintenance is a series of tasks to repair defects found in equipment. Corrective maintenance starts when additional problems found during a separate work order. Such as, during an emergency repair, as part of a routine inspection, or in the process of carrying out preventive maintenance, a technician discovers other problems that need to fixed before other problems occur. During the implementation of corrective maintenance work, assets are repaired, restored or replaced.

   Advantage:
   - Reduce short-term costs
   - Minimal planning
   - A more straightforward process, because it only acts when a problem occurs

   Disadvantage:
   - Stop the operation
   - Higher long-term costs
   - Uncertainty in the equipment used to the shortcomings unpredicted[8]

4. Breakdown Maintenance

   Breakdown Maintenance is maintenance performed on equipment that is damaged or fails. The differences from something like preventive maintenance, which is done to keep something running because the purpose of breakdown maintenance is to fix something that is completely not working.

   Sometimes maintenance breakdowns are carried out due to unplanned events. For example, if a machine breaks down, maintenance is carried out due to an urgent need for the machine to operate again. The most straightforward maintenance strategy is 'maintenance of disorders'. The assets intentionally run until they fail. When a failure occurs, reactive maintenance is carried out to repair the asset and return it to full operation. This approach is common when equipment failure does not significantly affect operations or productivity.

   Advantage:
   - Minimise maintenance costs by cutting preventive maintenance

[7] Ibid.

[8] The Realtiem Report, "*Advantages and Disadvantages of Corrective Maintenance*" (https://www.hansfordsensors.com/the-pros-and-cons-of-different-maintenance-strategies/, August 26, 2019)

- Reduce the cost of replacing disposable items
- A simple way to understand when maintenance is needed

Disadvantage:

- Security problems that can occur due to unplanned failures
- Unpredictable costs due to damaged parts that unpredicted
- Difficult to find the source of the problem[9]

2.8 Method for Developing Maintenance

The EU (European Union) has recently introduced the pressure equipment directive, which is a standard for design and construction of pressure equipment. The EU has no similar standard for the in-service phase. The RIMAP project will develop the technological basis for a standard for risk based maintenance and inspection planning.

Risk based inspection and maintenance planning is a multidisciplinary task. It requires a team, where all necessary competencies are represented and expertise are available. Another important issues is the regular evaluation to assess the performances of the maintenance and inspection activities based on the new data that becomes available from these activities. The steps in the process above are the same for all involved industry sectors.

The RIMAP projects provides guidelines on how to perform risk based inspection and maintenance planning for all types of equipment : active components, static components, as well as instrument protective functions.

Figure 2.11 shown the illustrates how different methods of analysis are applied to each type of equipment. The steps required to perform maintenance and inspection planning are similar for each type of equipment.

RIMAP recommends the use of the expected scenario in analyses. It is essential that the choice of approach is made before the analysis starts and that the same method is used consistently throughout the analysis. If not, this will affect the choice of risks that will be mitigated. This may lead again lead to a sub-optimal maintenance and inspection plan.

[9] UpKeep, "*Breakdown Maintenance*" (https://www.onupkeep.com/learning/maintenance-types/breakdown-maintenance, Accedded on August 26, 2019).

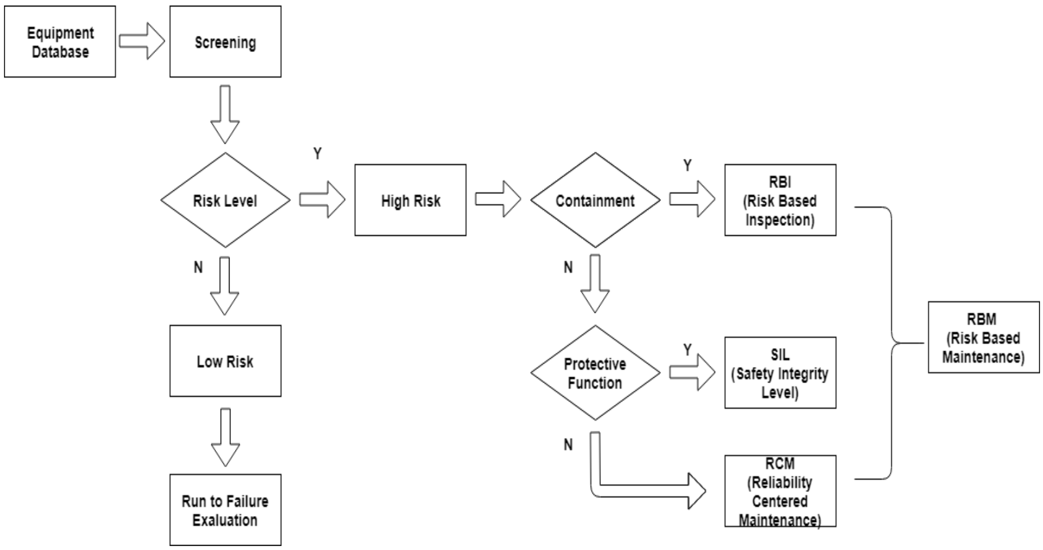

Figure 2. 11 Structure of Analysis *(Angelsen, et al., n.d.)*

Probability of failure (PoF) is a number of methods for determining the probability of failure are discussed (expert judgement, rate models, statistical, physical models, etc.). The PoF assessment enters into the analysis in different ways for the static equipment, instrument protective functions and active components:

- Static equipment: For trendable degradation mechanisms, the acceptable risk is combined with the consequence of failure to determine a PoF limit. The PoF limit is combined with the damage rate to obtain a maximum time to inspection.
- Instrument protective functions: For instrument protective functions the risk assessment is used to determine a requirement on availability. This limit is then used to determine maintenance strategies that meet the requirements.
- Active components: The PoF assessment, given a certain maintenance program, is combined with the CoF (Consequence of Failure) assessment to obtain a risk for the given maintenance program.

Consequence of failure (CoF) is a set of requirements to CoF assessments have been formulated. Complying with the requirements implies that the RIMAP procedure has been followed. Methods have been provided for assessing :

- Safety – instant consequences on humans within or outside the plant's area.

- Health consequences – long term effects on humans within or outside the plant's area.
- Environmental consequences and business consequences of failure.
- Financial consequence of failure.

The consequence assessment applies to all equipment types (rotating, static, instrument protective functions) and to all industry sectors represented in the project. The methods are easily extended to other industry sectors.

2.9 Society of Automotive Engineers (SAE International)

Society of Automotive Engineers (SAE) is a professional association that also develop the standard for the engineering industry, with a particular focus on transport sectors. The purposes to help industry with physical assets, such as machines that will do the maintenance well and also increase the lifetime of the asset.

2.9.1 SAE JA1011 (Evaluation Criteria for Reliability Centered Maintenance (RCM) Process)

The criteria in SAE JA1011 are based in the RCM process established by Nowlan and Heap in 1978. Besides, three documents that closely followed the original process were used extensively as sources; US naval aviation's MIL-STD-2173(AS), NES 45, and RCM II by John Moubray.

The standard requires the following seven steps to be performed in sequence (explained in section 2.5.4). However, the process assumes that the asset concerned already has been selected and defined. The SAE JA1011 does not provide any criteria for the process used for selecting and defining the asset.

2.9.2 SAE JA1012 (A Guide to the Reliability-Centered Maintenance (RCM) Standard)

SAE JA1012 is used as a guideline standard in the RCM process and defines each of main criteria listed in SAE JA1011 and summarises the additional processes that must be analysed sequentially in order to apply the RCM method to the assets.

2.10 Reliability-centred Maintenance

2.10.1 History

After World War II, the industry has experienced much progress. Especially in terms of awareness of the relationship between the failure of an asset with maintenance and the quality of the final quality product. With this in mind, the industry will ultimately increase asset capability

and minimise operational and maintenance costs needed. This change requires improving the new maintenance management system and developing the existing system to bring up a relevant discipline, namely RCM (reliability-centred Maintenance).
In the late 1950s, the American civil aviation industry adopted preventive maintenance methods. The program is run according to resources and based on a technical system that has a system that estimates doing maintenance on time. However, this number of flights suffered many types of damage that could not avoid during operations with preventive methods. As a result, this has reduced the reliability and safety of the aviation industry itself. Of the cases of failure that often occur, the Federal Aviation Agency (FAA) researches to analyse failures in aircraft operating systems. At that time, it found that reducing failure on the aircraft through changes in the type or frequency of operating activities was unsuccessful.

The next stage, in 1967, the FAA produced a document containing the instructions for estimating and developing a maintenance program or called MSG-1 (Maintenance Steering Group). Two years later, the MSG-2 system was announced and introduced. Then MSG-2 was introduced in military aircraft, starting from the S-3 Lockhead, then the P-3, and MacDonnell F4J. The MSG system that introduced and implemented succeeded in producing a more advanced technical system and a better comparison of operating hours after implementation on several American-owned aircraft. Maintenance costs after the application of MSG also cost significantly without reducing the reliability of an asset.
In 1978, RCM first applied to the US Navy ship - USS Roark. In the following years, RCM became a maintenance system that relied on other ships from the US Navy. In the mid-1980s, maintenance programs referred to the RCM method and developed by the United States Army, then in the Air Force and the Navy. The RCM standard used by the US Department of Defense published in 1984 in a Military Standard document and Military Specifications (Marcin K., 2017). RCM was found to be the most efficient strategy compared to the monitoring of existing maintenance strategies.

The following in **Table 2.1** is a success story of the RCM implementation that has many impacts on the state of maintenance and financial benefit.

Table 2. 1 Success Story of RCM Implementation

No	Year	Object	Result	Location
1	1980	U.S. Navy Common Support Equipment : three A/S32A-30A aircraft tow tractors, an A/M32C-17 mobile air conditioning unit, two mobile electric power plants (NC-10A/B/C and MMG-1A), and three hydraulic power supplies (T-5, T-7, and 55/E)	•On average, scheduled maintenance is reduced by 75% •On average, consumable usage is decreased 88% •The disposal of hazardous material is decreased 84%	USA
2	1994	Bonneville Power Administration (BPA) : transmission and distribution facilities	The success of the RCM program at BPA has been based on reducing maintenance tasks and maintenance backlog (more efficient). The result shows the cost savings of up to 40 %	USA
3	1995	Royal Navy	The maintenance has been converted to RCM then the result are affected in: •Financial savings of up to 40%. The total savings of £218m were derived from the following programmes: T22 and T23 Frigates, T42 Destroyers, HUNT Class MCMV, Single Role Mine Hunter, SSN. •The number of overdue maintenance tasks across the surface fleet to be reduced from 60,000 to less than 10,000.	UK
4	2006	A Ferrochrome Manufacturing Company	Reduces the maintenance costs by 20% of total manufacturing costs. From $777.307 in December 2006, $437.528 in January 2007. The maintenance costs for october 2007 to January 2008 averaged $459.400 per month after the implementation of RCM	South Africa
5	2010	The sodium chloride plant : Feed Water Pump, Fire Tube Boiler, Maintenance Labor Force	The results show that the labor cost decreases from $ 220.800/year to $ 295.200/year (about 25.2% of the total labor cost). The Maintenance planning results indicate a saving of about 80% of the total downtime cost as compared with that of current maintenance. The results show that about 22.17% of the annual spare parts cost are saved.	Egyptian Minerals and Salts Company , El-Fayoum, Egypt
6	2014	Air Compressor Unit	RCM maintenance schedule results in the overall saving of 15.57% of existing maintenance	Thermal Power Plant Khaperkh

			costs. The annual saving approximately $ 1840	eda Nagpur, India
7	2014	PEA Power Distribution System	The Result show cost savings of up to 11%, reduces up to $ 1.305.160	Bang Pa In, Thailand

RCM itself is a qualitative method for determining applicable preventive maintenance tasks and is an effective way to maintain the main functions of selected components or systems. RCM focuses on maintenance only on items that affect the reliability of the system, thus making the maintenance program costs effective in the long run. Because the results of RCM based on the context of the operation (Marcin K., 2017).

In 1996, SAE (Society of Automotive Engineers) began making standards for the RCM method. SAE International issued in 1999 a standard, SAE JAS1011 and in 2002, SAE published the SAE JA-1012.

2.10.2 Component of RCM

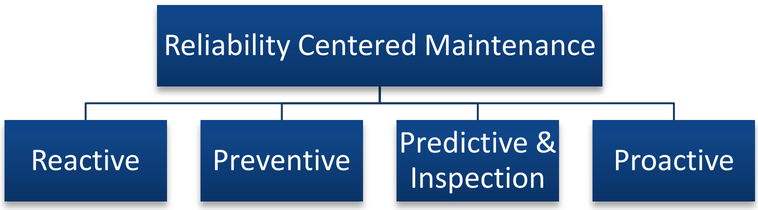

Figure 2. 12 Component of RCM *(Gupta & Mishra, 2018)*

RCM consists of a mixture of reactive maintenance practices, such as time-based, condition-based, and proactive maintenance. This maintenance strategy is applied integrally with other maintenance strategies to take advantage of the strength of each strategy to maximise the reliability of facilities and equipment while minimising life-cycle costs. **Figure 2.12** shows how all strategies are in one RCM method.

RCM as a maintenance theory is modern and developed because it requires an organised maintenance program. Such programs based on equipment maintenance needs, which organised according to their interests. RCM also manages available human and financial resources according to the importance of the equipment, that is, according to the loss or risk that can be caused by its failure. Therefore this strategy is used to improve efficiency by increasing equipment reliability.

2.10.3 7 Question of RCM

RCM can also interpret as a process used to determine what must be done to ensure that each physical asset operates appropriately following its design and function. RCM answers seven main questions to the system under study. The seven questions are as follows:

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

Explanation: Before it is possible to implement RCM, a function definition determine for each asset and operational standards that must achieve. The process of using it in the context of operations can be carried out by determining what wants to be needed and ensuring that assets can meet the needs. What is expected by the asset user can divide into two categories, namely:

- The main functions, including issues such as speed, results, capacity, product quality, and services.
- Secondary functions, assets are expected to do more than fulfil their primary function. Can be expected to have functions in the fields of safety, control, comfort, structural integrity, economy, protection, operational efficiency, and others.

2. In what ways does it fail to fulfil its functions (functional failure)?

Explanation: Functional failure is a component failure to meet the expected system function. Functional failure achieved by adopting an appropriate approach to failure management. In the RCM process, there are two levels carried out, namely:

- Identifying conditions that considered as fail conditions
- Ask about events that can cause assets to fail

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

Explanation: In the previous stage, functional failure identified. Next is to try to identify the possibility of failure. The causes of failures in components that have failed and do not meet operational standards are called failure mode.

4. What happens when each failure occurs (failure effect)?

Explanation: Failure of the component will have an impact on work operations. This fourth step is an illustration that will occur when a failure mode occurs. This description must include all the information needed to support an evaluation of the consequences of failure.

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

Explanation: Failure that occurs in an asset will have consequences. Therefore, asset users will try to avoid these failures. If the failure does not have a significant effect, usually the user will decide not to do routine maintenance. The high strength of RCM is to recognise that the consequences of failure are far more important than their technical characteristics. The RCM process classifies these consequences into four groups, shown in **Figure 2.13.**

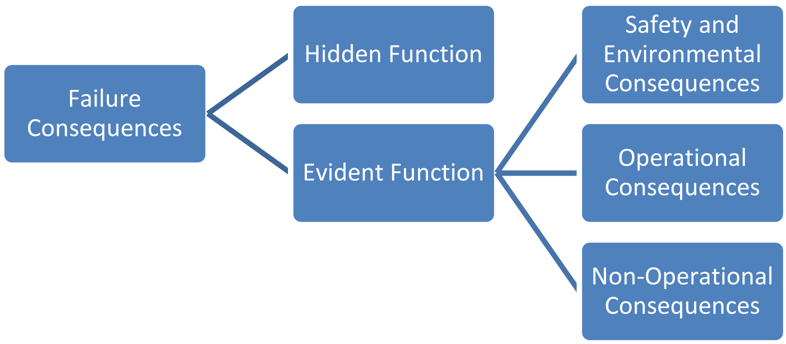

Figure 2. 13 Failure Consequences Categories

6. What can be done to predict or prevent each failure (proactive task)?

Explanation: the proactive task is a task that is carried out before a failure occurs, to prevent items from entering a state of failure. Proactive tasks perform traditionally or predictive and preventive. RCM uses the term Scheduled Restoration.

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

Explanation: A default action is a state of failure and chooses when it is not possible to identify a practical, proactive task. Default actions include failure-finding, re-design, and run-to-failure (Moubray, 1997).

2.10.4 Failure Mode, Effects, and Criticality Analysis (FMECA)

FMECA methodology is an advanced level of FMEA designed to assess the risk associated with all failure modes. The objective of FMECA is to design maintenance procedures required to eliminate points of failures as well as any catastrophic or critical consequence of such failures. The fundamental purpose is to initiate actions that reduce the likelihood of failure in the process.

FMECA also increases knowledge of a system and can improve the cost-effectiveness of preventive maintenance programs.

2.10.5 Steps of ABS Rules

ABS has reviewed the RCM analysis area and modified the method for marine applications. Available procedures and compliance with recognised standards are SAE JA1011, SAEJA1012, IMO Annex 3 and Annex 4 for implementing the Reliability-centered Maintenance (RCM) process (Conachey & , 2004). This is the following step of implementing RCM by ABS rules:

1. System Modeling, Functions and Functional Failures

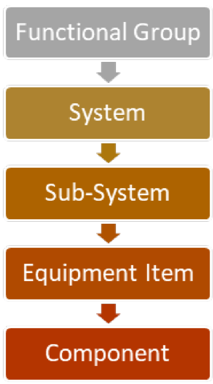

Figure 2. 14 Functional Hierarchy

The first step will require an analysis of the operation mode of the ship and the functional system of the main engine. The system will be modelled as a hierarchy for FMECA purposes, at the next step. ABS has ordered in hierarchical, as in **Figure 2.14**. A component defined as the lowest level of the functional hierarchy that can identify the functions of the group, failure mode, and physical units that can be considered preventive maintenance planning.

The system block diagram will visualise the structural hierarchy and identified each functional system. Then the various functional failures would be identified. ABS also has a template for various system subject to ABS rules and special periodical machinery survey requirements on vessels.

2. Conduct Failure Modes, Effects, and Criticality Analysis (FMECA)
   The next step is to show the consequences caused by the failure mode. In ABS Guidance also has the classification of effect failure. **Table 2.2** shown the severity level, from no effect, two progressive functional degradations to complete loss of function. From the approaches, the certification process would be easier to determine the failure effects on functional groups when a component failure occurs.

Table 2. 2 Example of Consequences/Severity Level Definition *(ABS, 2016)*

Severity Level	**Description for Severity Level**	**Definition for Severity Level**
1	Minor, Negligible	Function is not affected, no significant operational delays, Nuisance.
2	Major, Marginal, Moderate	Function is not affected, however failure detection/corrective measures not functional. OR Function is reduced resulting in operational delays.
3	Critical, Hazardous, Significant	Function is reduced, or demaged machinery, significant operational days
4	Catastrophic, Critical	Complete loss of function

Probability of other elements of risk is the frequency of failure mode. To prevent failure happens, collecting data of functional failure is the answer. ABS takes a qualitative approach to recommend frequency ranges, as shown in **Table 2.3.**

Table 2. 3 Example Probability of Failure Criteria *(ABS, 2016)*

Likelihood Descriptor	Description
Improbable	Fewer than 0.001 events/year
Remote	0.001 to 0.01 events/year
Occasional	0.01 to 0.1 events/year
Probable	0.1 to 1 events/year
Frequent	1 or more events/year

Next step is the preparation of the risk matrix. The risk matrix is a risk level table organised based on the combination of consequence level and frequency of failure. The standard used to determine the risk matrix is derived from ABS Guidance in **Table 2.4.**

Table 2. 4 Example of Risk Matrix *(ABS, 2016)*

Severity Level	Likelihood of Failure				
	Improbable	Remote	Occasional	Probable	Frequent
4	Medium	Medium	High	High	High
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

If all step of analysis of failure mode, effects, and criticality analysis has been completed. So the result of the analysis needs to be filled into the worksheet. ABS requires the application of a bottom-up FMECA, as shown in **Table 2.5.**

Table 2. 5 Bottom-up FMECA Worksheet *(ABS, 2016)*

No.: XX	**Description**: Pump					
Item	**Failure Mode**	**Causes**	**Failure Characteristics**	**Local Effect**	**Functional Failures**	**End Effects**

No.: XX	**Description**: Pump				
Item	**Matrix**	**Severity**	**Current Likelihood**	**Current Risk**	**Failure Detection/ Corrective Measures**

2.10.6 Maintenance Task Allocation and Planning

Maintenance task allocation and planning is the deliverable of this thesis. There are maintenance task categories for selecting the maintenance tasks and maintenance task interval to determine the interval of maintenance.

1. Maintenance Task Categories

   Maintenance task allocation and planning generated from the RCM analysis are divided into several categories based on location and parties required to carry out maintenance activities, including:

   - Category A, maintenance activities can be carried out directly by the crew even when the ship is in operational (sailing).
   - Category B, if a component has been in the maintenance schedule or has a failure, the shipowner is required to perform maintenance and repair of the ship in a non-operational condition. The maintenance may need shipyard equipped with facilities for ship repair. The owner is also required to be accompanied by the vendor during maintenance activities to ensure that existing maintenance activities are under existing standards on the components themselves.
   - Category C, maintenance activities on the components must be carried out when the ship is not operating. Maintenance must be carried out using repair and maintenance facilities at the dry dock.

2. Maintenance Task Interval

   Maintenance Task Interval is the period-time of maintenance performed on each component. Task intervals derived from RCM analysis do not need to be following the existing maintenance schedule (calendar-based maintenance schedule). This needs to be integrated with the existing maintenance schedule because the task interval can be done either shorter or longer than the existing schedule depending on several criteria as follows:

   - Maintenance activities with high safety and environmental consequences, if the failure occurs, the maintenance interval should be shorter than the existing maintenance schedule to ensure that the possible failure of the components will not dangerous during work operations.
   - If Maintenance activities with the consequences of disruption of work operations when a failure occurs, then the maintenance interval can be shorter or longer than the

existing maintenance schedule. However, when making a decision the maintenance interval schedule is longer than the existing schedule, this must get the approval of the party responsible for maintenance in the company.

In analysing the maintenance task and time interval, it needed to fill into a maintenance worksheet as shown in **Tabel 2.6.**

Table 2. 6 Example Maintenance Task Selection Worksheet *(ABS, 2016)*

Failure Mode	Failure Characteristics	Hidden/ Evindent	Effects			Risk Characterization			Task Selection			
			Local	Functional Failure	End	S	CL	CR	Proposed Action(s)	PL	PR	Disposition

If all the steps in the maintenance task allocation and planning analysis have been completed, then it is necessary to conclude from the results of the analysis. The following worksheet is a summary of maintenance tasks shown in **Table 2.7.**

Table 2. 7 Summary of Maintenance Tasks *(ABS, 2016)*

Maintenance Category : Category A, B or C Functional Group : Indicate group name, e.g., Propulsion System : Indicate system name Equipment Item : Indicate equipment item name Component : Indicate component name							
Task	Task Type	Item No.	Risk		Frequency	Procedure No. or Class Reference	Comments
			Un-mittigated	Mittigated			

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CHAPTER 3
RESEARCH METHODOLOGY

3.1 Research Methodology Flow Chart

The methodology flow chart shows all of the steps for this final project research. The steps of this methodology shown in **Figure 3.1.**

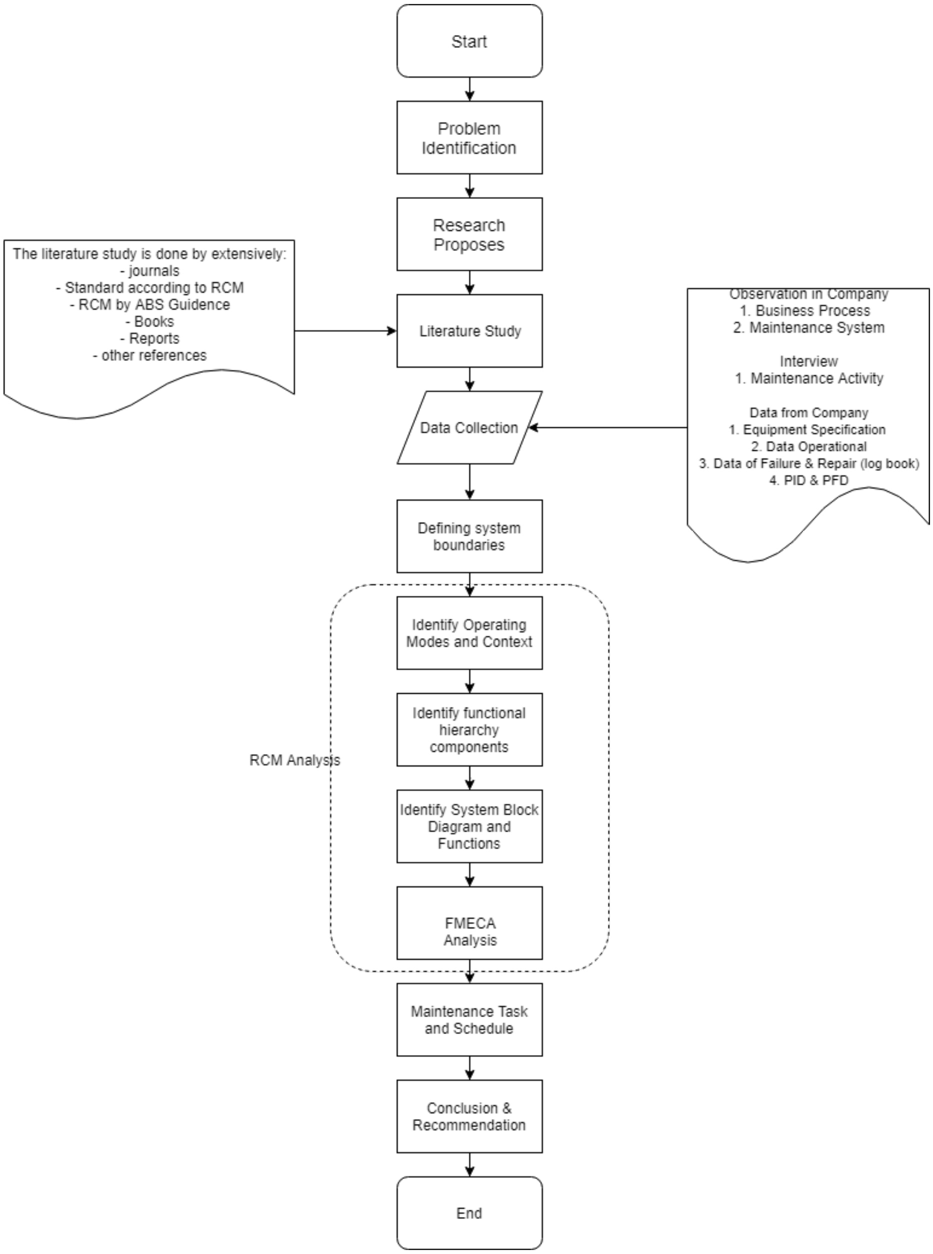

Figure 3. 1 Flow Chart of Methodology

3.2 Problem Identification

Identify the specific problem and objectives of the thesis. The main problem comes from the existing condition compared to required condition (Study Case). In this thesis will examine the RCM method for the main engine of Tugboat owned by PT. X.

3.3 Research Purposes

Research purposes obtained through problem identification. The Deliverable of this thesis would be the maintenance task and maintenance schedule.

3.4 Literature Study

The literature study needs to be done to obtain information as a scientific base and to support the analysis of the research. The literature study is done by extensively reading journals, Standard according to RCM Method, Books, Reports, and other references.

3.5 Data Collection

After doing the literature study, selecting a system and collecting data performed. There are two categories to collect the data. The categories explained in down below.

a. Primary, Data originating from the original or first source
b. Secondary, Data that refers to information gathered from existing sources. Secondary data sources are documentation, government publications, industry analysis, websites, oreda and so on.

3.6 Defining System Boundaries

After knowing the system & data to be studied, the next step is to determine the system boundaries established. System Boundaries used to determine the system to be examined in four main systems that exist on the main engine

3.7 Identify Operating Modes and Context

The operating mode is the operational state the vessel is in, such as cruising at sea, entering or departing a port. The identification of operating mode divided into four categories, namely:

- Environmental Parameters: based on operational area of the Tugboat. X
- Manner of Use: Based on operating system on Tugboat. X
- Performance Capability: Based on project guide of main engine from PT. X

The functional interdependence of the selected systems within functional groups shall be described through the use of block diagrams.

3.8 Identify Functional Hierarchy Components

Asset register must be arranged according to their functions and each component to identify the functional hierarchy components. The register asset, it will be easier to determine component maintenance.

3.9 Identify System Block Diagram and Functions

FBD is used to describe the relationship between one function and another function in the system. In addition to showing the functions and parts in them, the FBD also explained the relationship and workflow between functions that make up the system and the settings that require the system. As a minimum, the block diagram is to contain:

- The partitioning of the functional group into systems, equipment items and components;
- All appropriate labelled inputs and outputs and identification numbers by which each system is consistently referenced;
- All redundancies, alternative signal paths and other engineering features that provide “fail-safe” measures.

3.10 FMECA Analysis

This stage is how implementing RCM by ABS rules step by step. Failure Mode, Effect and Critical Analysis (FMECA) utilizing with RCM method of ABS Rules. The following steps in implementing FMECA in this research are as follows:

1. Identification of Failure Modes

   A failure mode is how failure is observed. It generally describes the way the failure occurs and its impact on the equipment or system. All of the equipment item or component related causes of the identified failure modes are to be identified.

   When used in conjunction with performance specifications governing the inputs and outputs on the system block diagram, all potential failure modes can thus be identified and described. Failure shall be assumed by one possible failure mode at a time with the exception of “hidden failures” in which a second failure must occur in order to expose the “hidden failure”. A failure mode in an equipment item or component could also be the failure cause of a system failure. Since a failure mode may have more than one cause, all potential independent causes for each failure mode shall be identified.

2. Failure Effects
   The effects of the failure for each failure mode are to be listed as follows:
   - The Local Effect is to describe the initial change in the equipment item or component operation when the failure mode occurs
   - The Functional Failure is to describe the effect of the failure mode on the system or functional group
   - The End Effect is to describe the overall effect on the vessel addressing propulsion, directional control, environment, fire and/or explosion. One failure mode may result in multiple end effects.

3. Failure Detection
   The failure detection means, such as visual or audible warning devices, automatic sensing devices, sensing instrumentation or other unique indications, if applicable. The term “evident” is to be indicated. Where the failure detection is not evident, the term “hidden” is to be indicated.

4. Corrective Measures
   Provisions that are features of the design at any level to nullify the effects of a failure mode. Provisions which require operator action to circumvent or mitigate the effects of the failure mode shall be provided.

5. Criticality Analysis
   Current Likelihood is explained in five categories in determining the level of frequency of damage (failure mode). The five categories are improbable, remote, occasional, probable, and frequent.

   The risk level of each component is analysed using FMECA from ABS rules that obtained from a combination of the severity and likelihood descriptors in the risk matrix.

The analysis must be filled into bottom-up FMECA Worksheet to decide the maintenance task of the main engine of Tugboat. To fulfil the RCM decision worksheet, it needs to answer the RCM decision diagram, which consists of failure consequences and the maintenance task techniques.

3.11 Maintenance Task and Schedule

The result of this research is determines the maintenance task. The maintenance task and schedule based on the results of the analysis from the previous FMECA result.

3.12 Conclusions & Recommendation

The final step is to make the conclusion of the entire process that has done before and provide answers to existing problems, and suggestions are given based on the results of prevention this research. Based on the results of the analysis, it is determined that proposed actions or recommendations for corrective or maintenance actions taken against failures occur.

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CHAPTER IV
DATA ANALYSIS

4.1 Identification of Data Collection

The data retrieval process at PT. X is conducting in three ways, namely Observation in Company, Interview, and physical Data on the company. The data are explained down below.

1. Observation in Company
   - Maintenance System, How the company prevent the break downtime with PMS (Planned Maintenance System)
2. Interview
   - Maintenance Activity, How the company maintain the communication between the crew onboard and the superintendant
3. Data from the Company
   - Main Engine Specification, To know about the specification of each part that included into the main engine
   - Data Operational, To know about the operational history of the main engine
   - Data Failure & Repair (Log Book), To see frequently failure and repair history to each equipment
   - PID & PFD, To see the flow diagram of the system is consist of the main engine

4.2 Research Object

The first stage in the Reliability Centered Maintenance method is to select the object to be analysed. This study examined the X tugboat owned by PT. X. After screening the data in the company, the Basic main engine was selected. The data of tugboat owned by PT. X explanation down below.

Figure 4. 1 Tugboat owned by PT. X

General Information of Tugboat (This information based on ship register website)	
Built Year	: 1996
Type of Ship	: Tugboat
Flag	: Indonesia
LBP (m)	: 31.52
B (m)	: 10.6
H (m)	: 4.96
T (m)	: 4.15
GT	: 413
NT	: 124
DWT (ton)	: 422
Service Speed (knot)	: 12
Main Engine Specification	
Manufacture	: Wartsila
Number of Strokes	: 4
Number of cylinders	: 9
Power	: 2100 BHP
RPM	: 1000

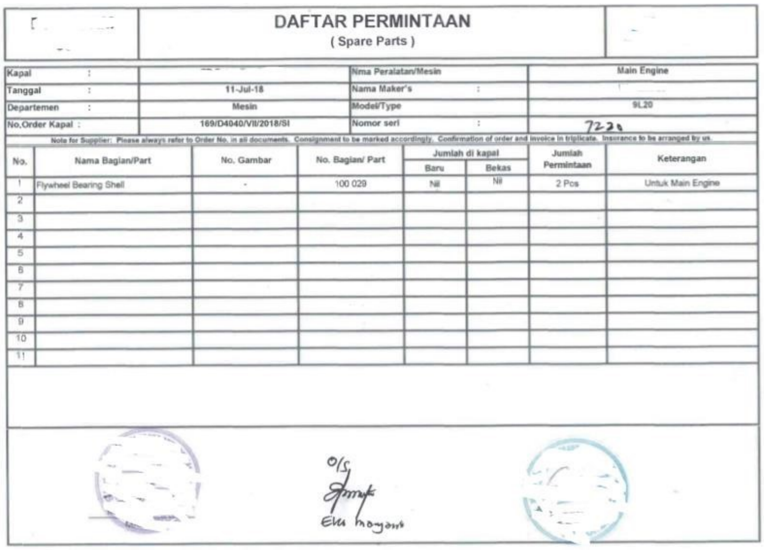
4.3 Data Historical Repair of Tugboat

PT. X is one of the companies that have implemented PMS that refers to OEM (Original Equipment Manufacturer). In the maintenance system of PT. X, already implemented the logbook system, where there is a historical repair of the main engine.

Historical Repair is data that includes components as well as details of damage to be done by the company as in **Figure 4.2.**

Data that has been obtained, there is a description of repairs and damage that will refer to the cause of the main engine break down. Therefore, the damage that has occurred will be evidence of the failure mode that will help to analyse the FMECA. Based on historical data repair above, it can identify the failure mode list that occurs on the main engine tugboat. List of failure modes shown in **Section 4.1.1.**

Also, there is an acceptance official report that descript the identification of damages and corrective actions performed by the crew of the ship. There is also evidence of the defect in the attached photos. The acceptance official report is one of the information that can help identify the cause of the damage (causes), the impact (local and end effects), and early detection for the failure in the FMECA Analyze. The acceptance official report is shown in **Figure 4.3.**


DAFTAR PERMINTAAN
(Spare Parts)

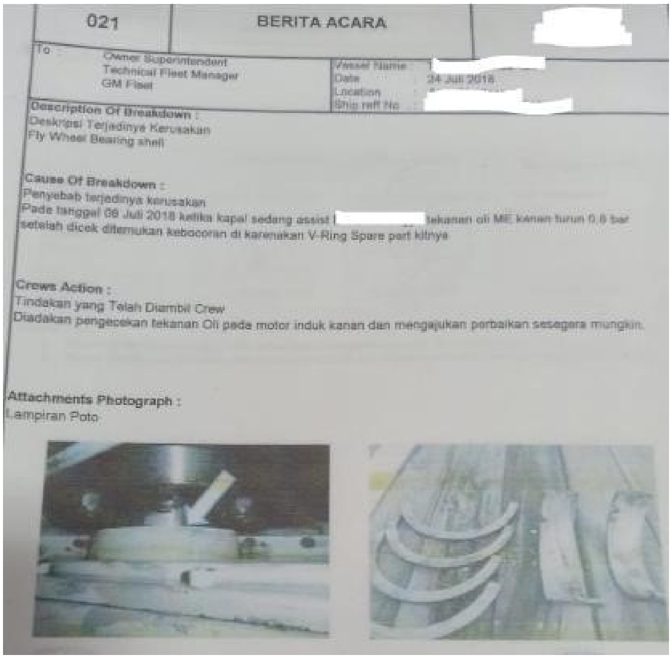
Kapal :		Nma Peralatan/Mesin	Main Engine
Tanggal :	11-Jul-18	Nama Maker's :	
Departemen :	Mesin	Model/Type	9L20
No.Order Kapal :	169/D4040/VII/2018/SI	Nomor seri :	7220

Note for Supplier: Please always refer to Order No. in all documents. Consignment to be marked accordingly. Confirmation of order and invoice in triplicate. Insurance to be arranged by us.

No.	Nama Bagian/Part	No. Gambar	No. Bagian/ Part	Jumlah di kapal		Jumlah Permintaan	Keterangan
				Baru	Bekas		
1	Flywheel Bearing Shell	-	100 029	Nil	Nil	2 Pcs	Untuk Main Engine
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							

O/S

Figure 4. 2 Historical Repair of Tugboat


021 BERITA ACARA

To : Owner Superintendent
Technical Fleet Manager
GM Fleet

Vessel Name :
Date : 24 Juli 2018
Location :
Ship reff No :

Description Of Breakdown :
Deskripsi Terjadinya Kerusakan
Fly Wheel Bearing shell

Cause Of Breakdown :
Penyebab terjadinya kerusakan
Pada tanggal 08 Juli 2018 ketika kapal sedang assist tekanan oli ME kanan turun 0.8 bar setelah dicek ditemukan kebocoran di karenakan V-Ring Spare part kitnya

Crews Action :
Tindakan yang Telah Diambil Crew
Diadakan pengecekan tekanan Oli pada motor induk kanan dan mengajukan perbaikan sesegera mungkin.

Attachments Photograph :
Lampiran Poto

Figure 4. 3 Acceptance Official Report of Tugboat

4.4 RCM Analysis by ABS Guidance

4.1.1. Operating Modes and Context

To determine the operating characteristics, the various operation modes for the main engine must be identified. The operation mode used to determine the operating context, as shown in **Appendix 1.**

The functional interdependence of the system selected in functional groups should be explained through the use of block diagrams in a narrative format to allow the failure effect to be understood. The list of failure modes for each system to be analysed will be developed. The development of an operational context is to consider the system setting, performance or standards of quality, environmental standards, safety standards, and Operation Way.

4.1.2. System Definition

The system definition involves portioning the functional vessel groups, system, subsystem, and component. The partitioning is to performed using a top-down approach until a level of detail is reached to identify the boundaries of the components. The partitioning for this research shown in **Appendix 2.**

4.1.3. System Block Diagrams and Functions

The block diagram is showing the functional flow sequence of the functional group, technical understanding of the functions, and operation of the system and for subsequent analysis. The system block diagrams can also be known effects and sequences of events that will and may occur due to failures in the component. So in the event of failure, the system or another component that will be affected against the failure can be known from the system block. In **Appendix 3** is shown the Functional Block Diagram**.** Where explained the hierarchy of main engine components.

4.1.4. Identification of Functional Failures

When identifying functions, the applicable operating modes and the operating context is to be listed. The performance standard is to describe the minimum acceptable requirement for the operating context rather than design capability. Performance standard divided into two categorised, Primary functions and Secondary functions.

A list of functional failures for each function identified for each functional group, system, and component. Each functional failure is to be documented in a functional failure statement that contains a verb, object, and functional deviation. The functional failures are to be shown in **Appendix 4.**

4.1.5. Failure Mode Effects and Criticality Analysis (FMECA)

For each failure mode, the FMECA is to indicate all functional losses, severity, probability of failure and their resulting risk. The consequence categories are to be considered in the FMECA when the failure mode directly initiates a consequence. FMECA analysis presented in **Appendix 5**.

4.1.5.1. Identification of Failure Modes

A failure mode is the manner by which a failure is observed. Since a failure mode may have more than one cause, all potential independent causes for each failure mode shall be identified. Each failure mode affects product performance, safety, reliability and has the potential to result in a catastrophic failure. The failure characteristics for the failure mode is to be identified as a wear-in failure, random failure, and wear-out failure. In this research, failure mode obtained from several sources, Historic reparation, OREDA, and manufacturing recommendations.

4.1.5.2. Failure Effects

The effects of the failure for each failure mode are to be listed as the local effect, the functional failure, and the end effect. When the failure detection is hidden and the system can continue with its specific operation, the analysis is to be extended to determine the effects of a second failure, which in combination with the first undetectable failure may result in a more severe effect. It is to be assumed for the analysis that any corrective measures provided are successful unless that corrective measure is the second failure whose effects are being analyzed.

4.1.5.3. Failure Detection

The following information is to be included in the failure detection/corrective measures column of the FMECA Worksheet:

i) The failure detection means, such as visual or audible warning devices, automatic sensing devices, sensing instrumentation or other unique indications, if applicable. The term "evident" is to be indicated.

ii) Where the failure detection is not evident, the term "hidden" is to be indicated.

4.1.5.4. Criticality Analysis

The criticality analysis is performed concurrently as part of the system design process. The criticality analysis begins as an integral part of the early design process and is updated as the design evolves. The criticality analysis produces a relative measure of the significance of the effect a failure mode has on the successful operation and safety of the system. The criticality analysis is completed after the local, next higher level, and end effects of failure have been evaluated in FMECA Worksheet (**Appendix 5**). Logic Tree Analysis shown in **Appendix 6**. Also the proposed Solution shown in **Appendix 7**.

The severity level for consequences are to be described and defined using the format shown in **Table 4.1**.

Table 4. 1 Consequence/Severity Level Definition Format

<table>
<tr><th>Severity Level</th><th>Description for Severity Level</th><th>Definition for Severity Level</th><th>Applicable to Functional Groups for</th></tr>
<tr><td>1</td><td>Minor, Negligible</td><td>Function is not affected, no significant operational delays. Nuisance.</td><td rowspan="4">Propulsion
Directional Control
Drilling
Position Mooring (Station Keeping)
Hydrocarbon Production and Processing
Import and Export Functions</td></tr>
<tr><td>2</td><td>Major, Marginal, Moderate</td><td>Function is not affected, however failure detection/corrective measures not functional. OR Function is reduced resulting in operational delays.</td></tr>
<tr><td>3</td><td>Critical, Hazardous, Significant</td><td>Function is reduced, or damaged machinery, significant operational delays</td></tr>
<tr><td>4</td><td>Catastrophic, Critical</td><td>Complete loss of function</td></tr>
</table>

Figure 4.4 shown the recapitulation of the severity level analysis conducted on the main engine of the tugboat X. There are 0% minor severity level, 7% major severity level, 47% critical severity level, and 46% catastrophic severity Level.

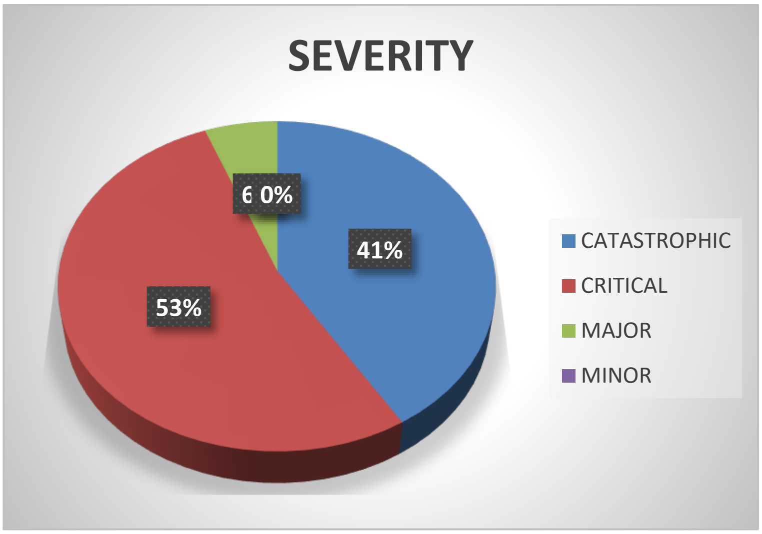


Figure 4. 4 Severity level Recapitulation

For the likelihood of failure, five likelihoods are described and defined shown in **Table 4.2**. Ranges based on the number of events per year are to be provided. From the classification data, then used as a reference in FMECA analysis as a level of critical equipment of every failure mode that occurs.

Table 4. 2 Probability of Failure Criteria

Likelihood Description	Description
Improbable	Fewer than 0.001 events/year
Remote	0.001 to 0.01 events/year
Occasional	0.01 to 0.1 events/year
Probable	0.1 to 1 events/year
Frequent	1 or more events/year

A risk matrix is to be developed using the example format shown in **Table 4.3.** The risk matrix is to be assigned a priority descriptor. The lowest risk ranking is to signify acceptable risk, and the highest risk ranking is to signify an unacceptable risk.

A risk matrix is to be developed for the functional groups and consequence categories. During the development of the risk matrix, the risk ranking for certain likelihoods and severity levels may vary when comparing the functional groups and consequence categories.

Table 4. 3 Risk Matrix

Severity Level	Likelihood of Failure				
	Improbable	Remote	Occasional	Probable	Frequent
4	Medium	Medium	High	High	High
3	Low	Medium	Medium	High	High
2	Low	Low	Medium	Medium	High
1	Low	Low	Low	Medium	Medium

Figure 4.5 shown the recapitulation of the risk level analysis conducted on the main engine of the tugboat X. There are 87% Medium risk level and 13% High risk level.

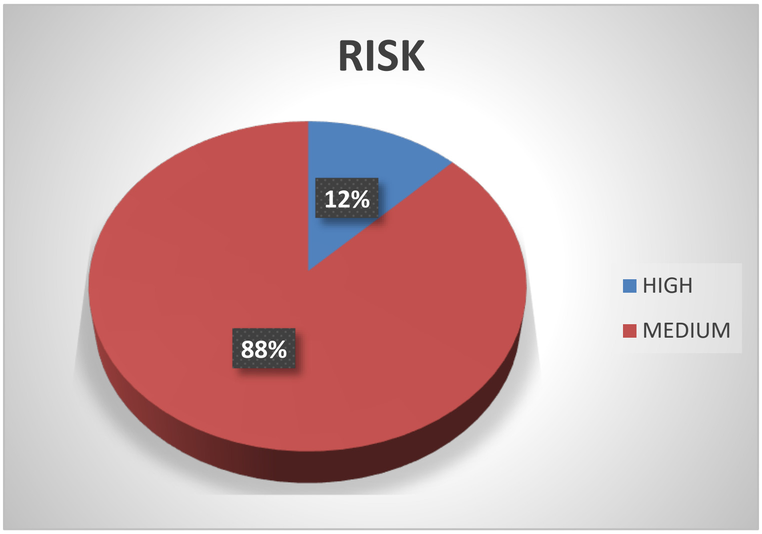


Figure 4. 5 Risk Level Recapitulation

4.1.6. Selection of the Failure Management Tasks

The maintenance tasks identified in each step are to be organized in accordance with the following suggested categories:

- Category A - Can be undertaken on location (at sea, offshore) by the onboard personnel
- Category B – Must be undertaken alongside by equipment vendors or with use of dockside facilities
- Category C – Must be undertaken in a dry dock facility

Every proposed action to address the failure mode that occurs in the FMECA analysis will be divided into several categories. This categorizing corresponds to the appropriate task type based on the maintenance recommendation. There are Preventive Maintenance (PM), Condition Monitoring (CM), Failure Finding (FF) and One-Time Change (OTC). Steps in categorizing treatment types based on logic tree analysis in ABS Guidance. The logic tree analysis is shown in **Appendix 6.** The result of logic tree analysis will use to specify proposed action in FMECA worksheet. FMECA Worksheet presented in **Appendix 7.**

Figure 4.6 shown the recapitulation of the maintenance category of FMECA analysis conducted on the main engine of the tugboat X. There are 41% of Category A, 59% of Category B and 0% of Category C.

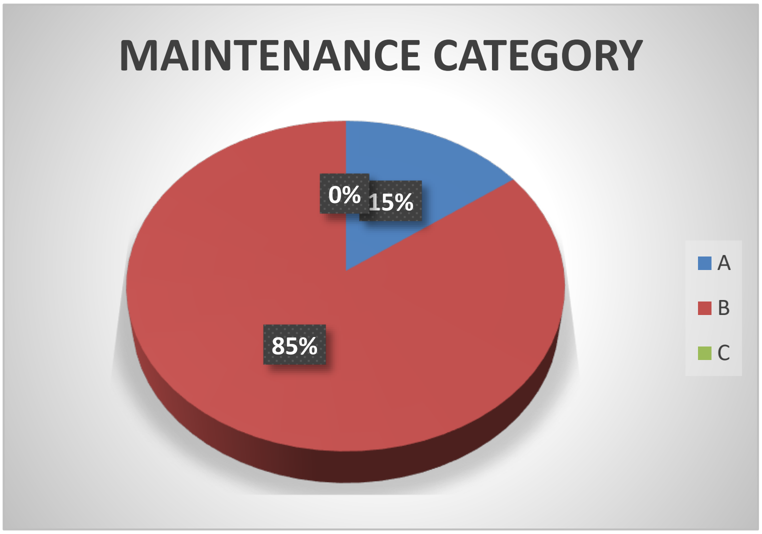


Figure 4. 6 Maintenance Category Recapitulation

Figure 4.7 shown the recapitulation of task type on the whole maintenance category. There are 62% of Preventive Maintenance (PM), 34% Condition Monitoring (CM), 4% of Failure Finding (FF).

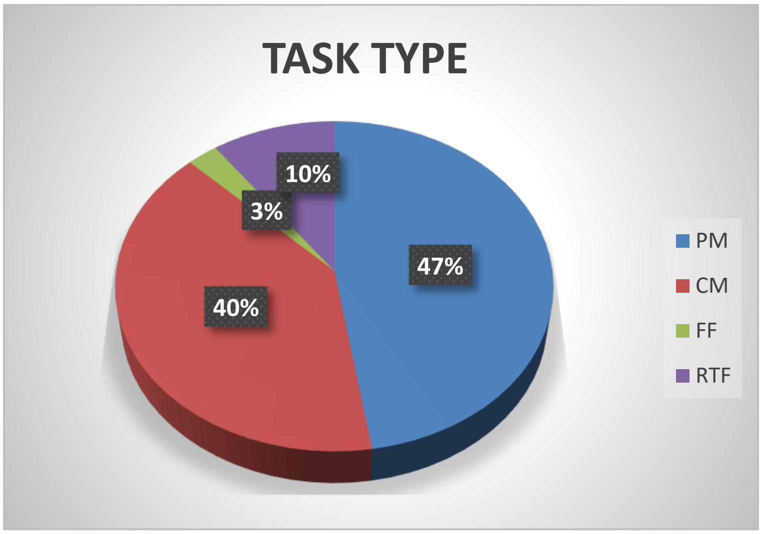


Figure 4. 7 Task Type of Maintenance Task

The summary of the maintenance task presented in **Appendix 8**. On the summary of maintenance task, each maintenance action is analyzed to determine the appropriate task type. Each task type is decided based on logic tree analysis in the ABS Guidance.

Figure 4.8 shown the recapitulation of task type from the Category A maintenance task. There are 29% of Preventive Maintenance (PM), 71% Condition Monitoring (CM), 0% of Failure Finding (FF).

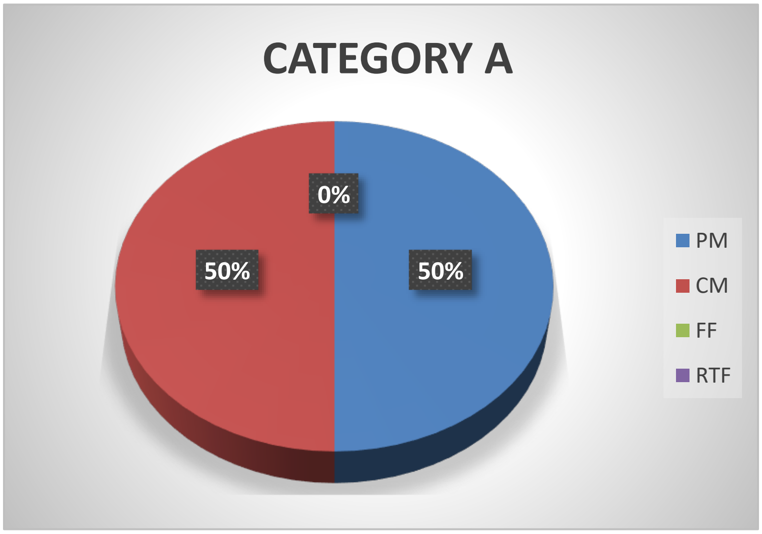


Figure 4. 8 Category A maintenance task

Figure 4.9 shown the recapitulation of task type from the Category B maintenance task. There are 75% Preventive Maintenance (PM), 20% Condition Monitoring (CM), 5% of Failure Finding (FF). Category C maintenance task has no task type.

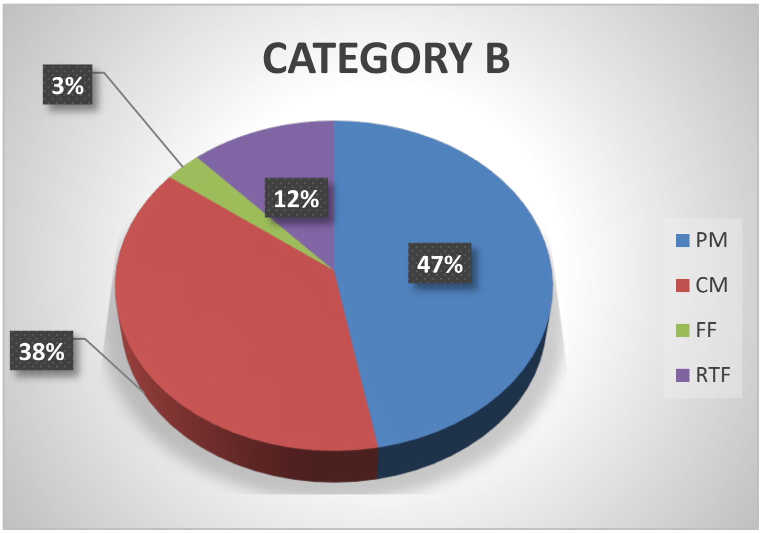


Figure 4. 9 Category B maintenance task

4.5 Comparison Study

Comparison study on the results of the analysis of treatment recommendations is done by comparing the risk of equipment before analysis (curren risk) with risk equipment with RCM analysis (projected risk). **Figure 4.10** shown the diagram Current Risk. There are 87% Medium risk level and 13% High risk level. Also **Figure 4.11** shown the diagram projected risk. There are 53% Medium risk level and 47% Low risk level.

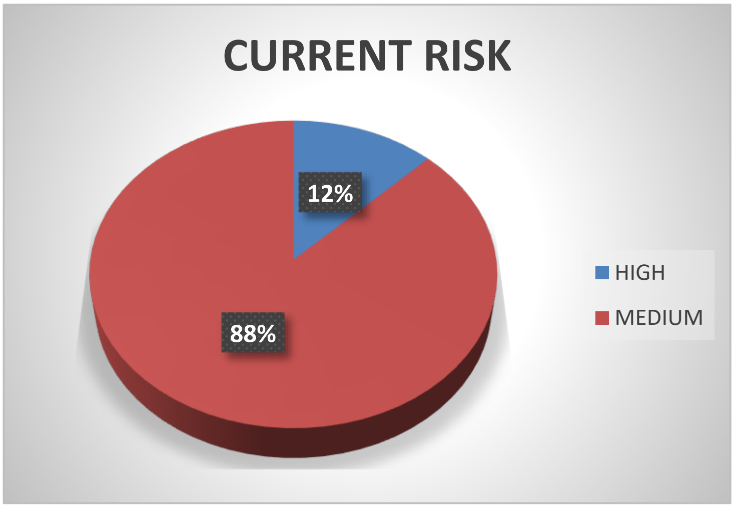


Figure 4. 10 Current Risk

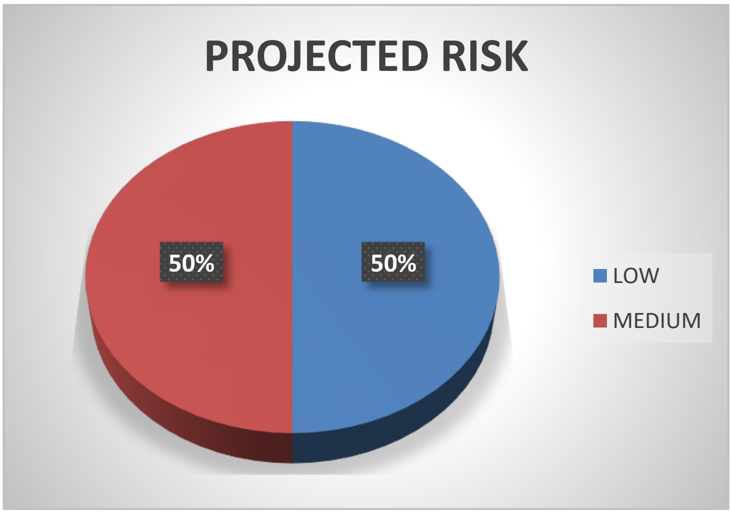


Figure 4. 11 Projected Risk

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CHAPTER V
CONCLUSION & SUGGESTION

5.1 Conclusion

The reliability-centred maintenance (RCM) method is using to determining the maintenance task for Main Engine Tugboat X. This analysis using historical repair list data in 2018 and OREDA data in this analysis. Based on the maintenance task allocation and planning analysis, the following results are obtained:

1. There are three maintenance task categories, which the main engine of tugboat X has 6 task list in category A, 34 task list in category B, 0 task list in category C.
2. In all three categories, there are 40 task lists acquired. Which the type of treatment presentation of failure mode is 47% (19 task) of Preventive Maintenance (PM), 40% (16 task) of Condition Monitoring (CM), 10% (10 task) of Run-to-Failure (RTF) and 3% (2 task) of Failure Finding (FF). Preventive Maintenance and Condition Monitoring maintenance are the main recommendations for this analysis to get the maximum operational time.
3. Based on the analysis, the projected risk of the main engine tugboat X has lower risk than before. Before the analysis, It has 88% Medium Risk and 12% High Risk. After the analysis, It has 50% Medium Risk and 50% Low Risk.

5.2 Suggestion

For the suggestion there are some improve for the more accurate research results, obtained:

1. In the development of this research required more specific failure data of Main Engine Tugboat X
2. Further data needs to be analyzed by considering the cost maintenance

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References

A., 2016. *Guide for survey based on machinery reliability and maintenance techniques.* Houston: American Bureau of Shipping.

Angelsen, S., Johansson, M., Pollock, A. & Vage, G., n.d. RIMAP (Risak Based Inspection and Maintenance for European Industries) The European Approach.

Conachey, R. M. & A., 2004. Development of RCM Requirements for the Marine Industry. *ABS Technical Papers.*

Conachey, R. M. & Montgomery, L. R., 2002. Application of Reliability-centered Maintenance Techniques to the Marine Industry. *ABS Technical Papers* .

D. & Raj, J., 2014. CBM, TPM, RCM, and A-RCM - A Qualitative Comparison of Maintenance Management Strategies. p. 50.

G. & M., 2018. Identification of Critical Components using ANP for Implementation of Reliability Cantered Maintenance.

Marcin K., Z. M., 2017. Reliability Centred Maintenance (RCM) - Basics of Implementation and general characteristics. *Journal of Machine Construction and Maintenance,* p. 101.

Mori, T., 2016. The Present Situation and The issues on tugboat business in Japan. *Univerity Marketing and Distribution Sciences,* p. 1.

Moubray, J., 1997. *Reliability-centred maintenance.* 2nd ed. s.l.:Industrian Press.

Nahim, H. M., Younes, R., Nohra, C. & Ouladsine, M., 2015. Complete Modeling for system of Marine Diesel Engine. *Journal Marine Science and Application.*

New, C. & Gay, R., 2012. RCM in the Royal Navy (RN) - Developing A Risk Based Policy for integrating safety and maintenance management. *Managing Reliability and Maintainability in the Maritime Industry.*

P&IClub, 2017. *P&I Loss Prevention Bulletin, Thinking Prevention of Engine Trouble,* s.l.: P&IClub.

Perhubungan, D., 2016. *Statistik Perhubungan 2016 Buku II,* Jakarta: Dinas Perhubungan Indonesia.

PT.X, 2018. *Annual Report 2018,* Jakarta: s.n.

S., Sri, I., M. & A., 2017. Mapping of Vessel Accident Characteristics in Indonesia Based on Investigation of KNKT. p. 2.

Appendix 1

Operating Modes and Context

<table>
<tr><td colspan="4">Operating Context of Diesel Engine</td></tr>
<tr><td colspan="4">This is a harbor tug that operating at port area. The engines is a 4-stroke with 2100 BHP at 1000 RPM.</td></tr>
<tr><td rowspan="2">Common Characteristics</td><td colspan="3">Operating Modes</td></tr>
<tr><td>At Sea</td><td>Maneuvering Alongside</td><td>Cargo Handling</td></tr>
<tr><td>Environmental Parameters</td><td>Nominal ambient air temperature: 25-30°C

FO, before engine driven fuel feed pump, min. 0,15 bar at temp. 45°C.

LO, before bearings, temp. 45°C at 4,5 bar and after engine approx.. 78°C

CO:
a. High temp. cooling water system before cylinder, approx. 83°C and temp. after engine, nom. 91°C
b. Low temp. cooling water system before engine min-max. 25-38°C</td><td>Nominal ambient air temperature: 25-30°C

FO, before engine driven fuel feed pump, min. 0,15 bar at temp. 45°C.

LO, before bearings, temp. 45°C at 4,5 bar and after engine approx.. 78°C

CO:
a. High temp. cooling water system before cylinder, approx. 83°C and temp. after engine, nom. 91°C
b. Low temp. cooling water system before engine min-max. 25-38°C</td><td>Not used</td></tr>
</table>

Appendix 1

Operating Modes and Context

<table>
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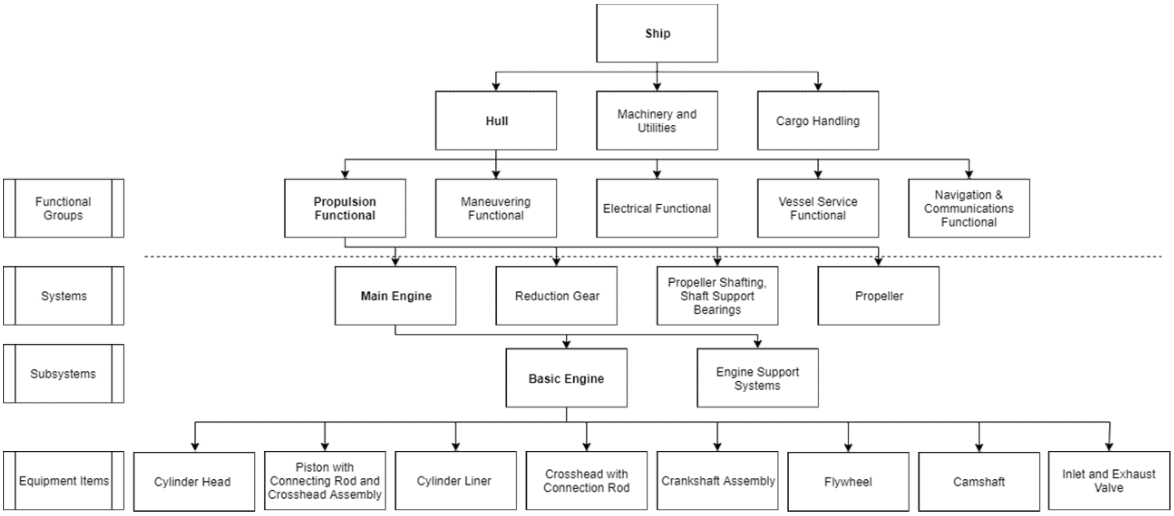
<tr><td rowspan="2">Common Characteristics</td><td colspan="3">Operating Modes</td></tr>
<tr><td>At Sea</td><td>Maneuvering Alongside</td><td>Cargo Handling</td></tr>
<tr><td>Manner of Use</td><td>Propels vessel at 12 knots at 85% of MCR. This harbor tug using 2 diesel engine.</td><td>Propels vessel from 2 to 10 knots, with reversing and stopping capabilities, and assists in</td><td>Not used</td></tr>
<tr><td>Performance Capability</td><td>To output 2100 BHP at 1000RPM; controllable from bridge, centralized control station</td><td>To output 2100BHP at 1000RPM; controllable from bridge, centralized control station</td><td>Not used</td></tr>
</table>

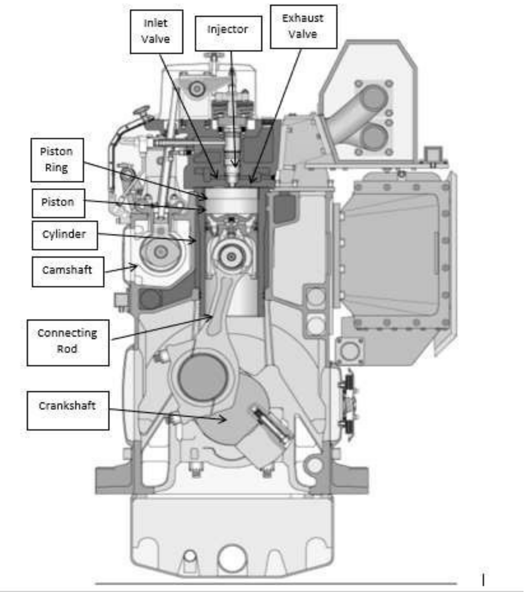
Appendix 2

Functional Hierarchy



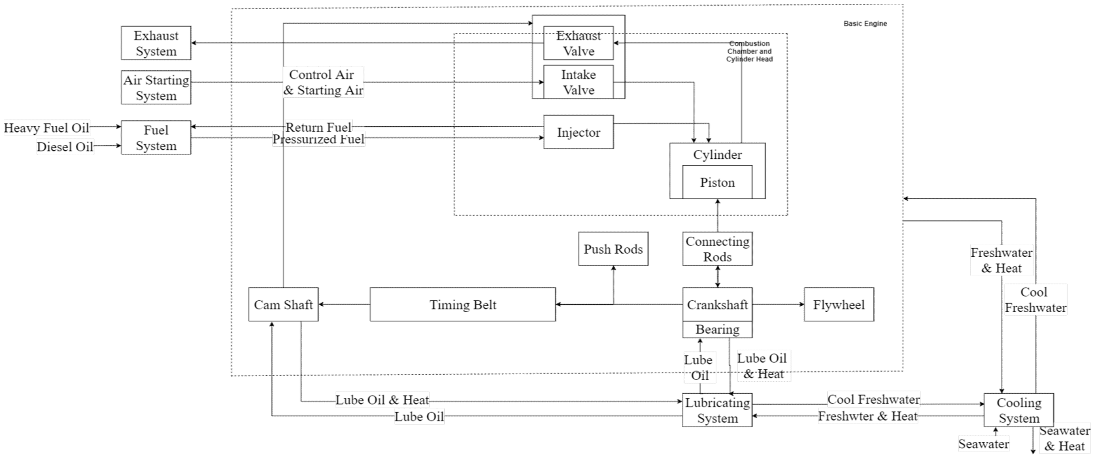
Appendix 3

Functional Block Diagram



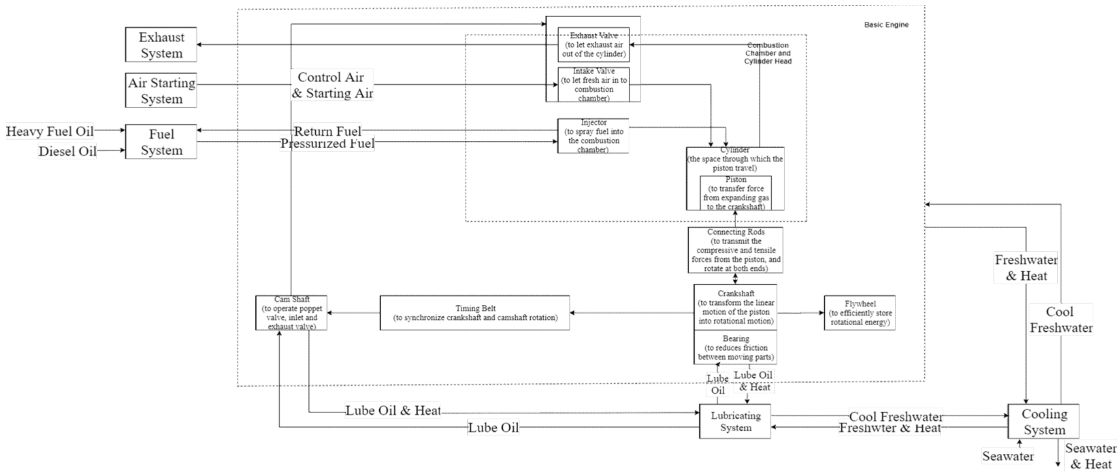
Appendix 3

Functional Block Diagram



Appendix 3

Functional Block Diagram



Appendix 4

Function Functional Failure List

Equipment Item: Medium speed engine for main propulsion, driving controllable pitch propeller				
Function			Function Failure	
Item No.	Functional Statement	Function Type	Item No.	Functional Failure
1	To Transmit 2100 BHP at 1000 RPM of power	Primary	1.1	Transmits less than 2100 BHP of power to the propulsion shafting
			1.2	Transmits more than 2100 BHP of power to the propulsion shafting
			1.3	Transmit less than 1000 RPM rotation during operation
			1.4	Transmit more than 1000 RPM rotation during operation
			1.5	No transmission of power to the propulsion shafting
2	To release exhaust engine gases after the turbochargers are to be in the range 330-368°C	Secondary	2.1	Exhaust gases are more than 330°C
			2.2	Exhaust gases are less than 368°C
3	To provide engine overspeed protection at 1200 RPM	Secondary	3.1	No activation of overspeed protection
			3.2	Overspeed protection activates at less than 1200 RPM
			3.3	Overspeed protection activates at more than 1200 RPM
			3.4	Overspeed protection activates and cannot be reset

<u>Appendix 5</u>

FMECA Worksheet

Function	Function Failure	Item No.	Failure Mode	Causes	Failure Characteristics	Risk: Local Effects	Risk: End Effects	Matrix Category Consequence	Severity	Current Likelihood	Curent Risk	Remark
1.1 To Transmit 2100 BHP at 1000 RPM of power	1.1 Transmits less than 2100 BHP of power to the propulsion shafting	1.1	Clogged fuel filter	The fuel filter removes any dirt from the fuel before it can get to the fuel injection system. It allows the fuel through under pressure but blocks dirt particles. Over time, the filter material will become dirty, and less permeable. This will restrict the amount of fuel that can get through it to the engine.	Wear Out Failure	If there is a problem caused by a clogged fuel filter, then it will show up as a fuel injection system error. Because of the fuel to the fuel injector is restricted.	Not changing the fuel filter regularly can lead to engine performance issues and start difficulties. These issues can usually be remedied by fitting a new filter.	Propulsion	Critical	Remote	Medium	O. F. Eker, F. Camci, and I K. Jennions, 2013. *Filter Clogging Data Collection* , UK: IVHM Centre, Cranfield University.
		1.2	Low Output fuel from Fuel Injector	The fuel injectors are responsible for delivering fuel to the engine. Low output fuel from the injector fuel caused by the fuel injector is clogged. The clogged fuel injector caused by fuel filter is worn out. Any fuel left in the injector to evaporate is another causes because it had leaving behind hard deposits inside the injector. Over time, these will eventually block the injector. When the fuel level that injects to the combustion chamber fluctuates drastically, the high and low rpm's will cause the engine to move in surges rather than slow and gradual movements	Wear Out Failure	If a clogged fuel injector continually disperses fuel to the engine, a time will come when it misses the fuel supply completely and the engine will misfire. The misfire will make the engine can quickly overheat and pre-ignite the fuel mixture	It leads to engine performance and starting issues	Propulsion	Critical	Remote	Medium	Dimitrios N. Tziourtzioumis & Anastassios M. Stamatelos, 2019. *Diesel-Injection Euipment Parts Deterioration* . Energies Journal.
		1.3	Leakage Crankshaft Seals	Combination of normal wear in the crankshaft and seal combined with the drying, hardening and shrinking of the main seal	Wear Out Failure	The crank seal purpose in keeping the oil that is constantly being used and tossed by the crankshaft as it rotates from leaking out of the engine's crankcase. When they fail they can cause leaks which can make a mess, even put the engine damage. Such as broken crankshaft because out of lubricating oil.	The part of the engine would be worn out before it should be and Engine oveheat	Propulsion	Major	Occasional	Medium	Piotr Bzura, 2018. Influence of Lubricating Oil Improves on Performance of Crankshaft Seals. Polish Maritime Research.

<u>Appendix 5</u>
FMECA Worksheet

Function	Function Failure	Item No.	Failure Mode	Causes	Failure Characteristics	Risk		Matrix Category Consequence	Severity	Current Likelihood	Curent Risk	Remark
						Local Effects	End Effects					
		1.4	Cracked Piston	Detonation is the cause of a cracked or broken piston. Loss of exhaust gas recirculation is the cause of detonation. If the combustion chamber loss of exhaust gas recirculation, combustion temperatures may exceed the octane rating of the fuel causing the air/fuel mixture to ignite spontaneously before the spark plug fires. The other causes are that can burn a piston: a lean fuel mixture, over-advanced spark timing, a bad knock sensor, low octane fuel or anything that causes the engine to run hotter than normal	Wear-out Failure	The cracked piston causing lose compression	Low compression caused low power	Propulsion	Critical	Remote	Medium	Ambrozik Tomasz & Lagowski Piotr, 2015. *Selected Failure of Internal Combustion Engine Pistons*. Logistyka.
		1.5	Demaged Piston Ring	This problem most often occurs in the top piston ring. Because it is exposed to the most heat from the combustion chamber. Anything that causes the fuel mixture to run lean or the engine to run hot can be a contributing factor	Wear-out Failure	The damaged piston ring can effect is excessive oil consumption and low power for acceleration	For the worse, it can be an overall loss of power	Propulsion	Critical	Remote	Medium	Ambrozik Tomasz & Lagowski Piotr, 2015. *Selected Failure of Internal Combustion Engine Pistons*. Logistyka.
		1.6	Breakage air inlet valve	In the operation, thermal and mechanical stresses are imposed on the inlet because of high temperature and pressure in the cylinder. These thermal and mechanical stresses are prime sources of valve failures at the sealing area. The movement of opening and closing also impart sliding friction leads to valve seat wear	Wear Out Failure	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Propulsion	Critical	Remote	Medium	Philip Kristanto & Rahardjo Tirtoatmodjo, 2000. The effect of temperature and Inlet air pressure on Diesel Engine Performance. Mechanical Engineering Departement, Petra Christian University
		1.7	Piston Slap	Piston slap is caused by worn pistons or cylinders, collapsed piston skirts, misaligned connecting rods, excessive piston to cylinder wall clearance, or lack lubrication resulting in worn bearings.	Wear Out Failure	Piston is commonly heard when the engine is cold and often gets louder when the vehicle accelerates. When a piston slaps againts the cylinder wall, the result is a hollow, bell-like sound.	It can lead to poor compression and power loss.	Propulsion	Critical	Remote	Medium	NAVEDTRA 14050a, 2016. Chapter 4 Engine Troubleshooting.

Appendix 5
FMECA Worksheet

Function	Function Failure	Item No.	Failure Mode	Causes	Failure Characteristics	Risk: Local Effects	Risk: End Effects	Matrix Category Consequence	Severity	Current Likelihood	Curent Risk	Remark
		1.8	Breakage Exhaust Valve	Valve failures is a fatigue failure. In the operation, thermal and mechanical stresses are imposed on the inlet and exhaust valve because of high temperature and pressure in the cylinder. These thermal and mechanical stresses are prime sources of valve failures at the sealing area. The movement of opening and closing also impart sliding friction on the valve and valve seat sealing area which leads to valve and valve seat wear. The frequency of exhaust valve failure is more than the intake valve. The exhaust valve is subjected to different stresses than the inlet valve. Exhaust valves are exposed to thermal stress more than the intake valve because the intake valve is virtually cooled by fresh air	Wear Out Failure	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Propulsion	Critical	Occasional	Medium	Yuvraj K. Lavhale, Prof. Jeevan Salunke, 2014. Overview of Failure Trend of Inlet & Exhaust Valve. International Journal of Mechanical Engineering and Technology (IJMET)
		1.9	Breakage cylinder head	The causes of cylinder head cracking is overheating. The rapid heating of the engine causes the head to expand and then contract as the engine cools. This puts a large amount of stress on the cylinder head, leading to cracks. Similarly, stressful operating conditions can lead to cracks, along with other engine problems.	Wear Out Failure	A number of issues can arise from a cracked cylinder head. Coolant can enter the cylinders and engine block through the crack. This can contaminate the oil, causing other major engine problems. It could also cause pitting and damage to the engine block. If the coolant enters the cylinder itself, it is often burned off in the exhaust, while damaging the cylinders.	Engine Stop	Propulsion	Catastrophic	Remote	Medium	Hojjat Ashouri, Babak Beheshti, & Mohammad Reza Ebrahimzadeh, 2016. *Analysis of Fatigue Cracks of Cylinder Heads in Diesel Engine* . Journal of Theoretical and Applied Mechanics.
		1. 10	Breakage cylinder liner	Cylinder liners may crack because of poor cooling, improper fit of pistons, incorrect installation, foreign bodies in the combustion space, or erosion and corrosion. Improper cooling, which generally results from restricted cooling passages, may cause hot spots in the liners, resulting in liner failure due to thermal stress	Wear Out Failure	The effect will be low firing or compression pressure and rapid wear of piston rings	Power Loss	Propulsion	Critical	Remote	Medium	K. Srinivasa Rao, K. Srinivas, B. Vinay, D. Aditya, K.V. Vamsi Krishna, & K. Siva Rama Krishna, 2015. *Analysis of Engine Cylinder Liners* . International Research Journal of Engineering and Technology (IRJET).

Appendix 5

FMECA Worksheet

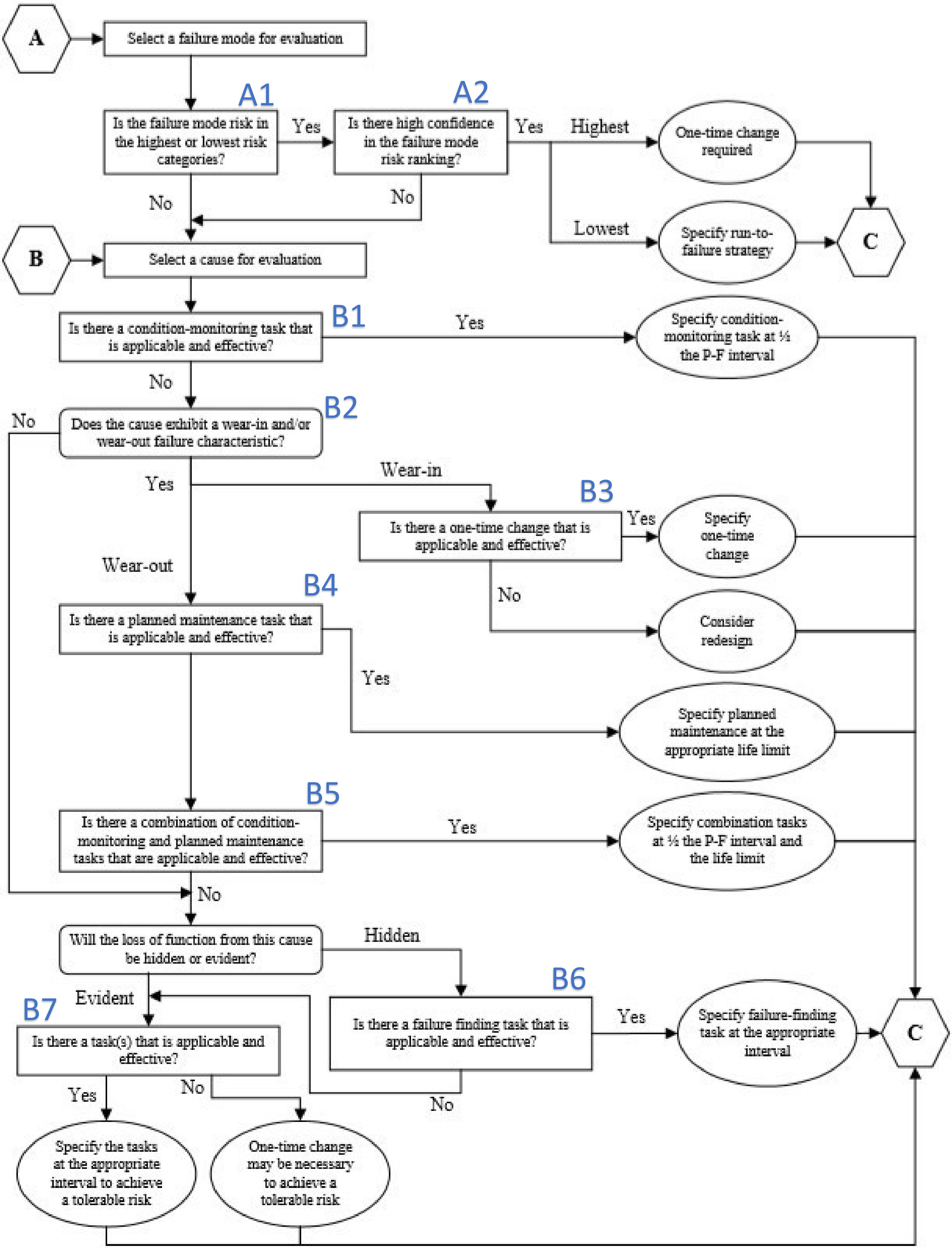
Function	Function Failure	Item No.	Failure Mode	Causes	Failure Characteristics	Risk		Matrix Category Consequence	Severity	Current Likelihood	Curent Risk	Remark
						Local Effects	End Effects					
	1.2 Transmits more than 1565 kW of power to the propulsion shafting	1.11	Overspeed	Due to sudden changes in the load on the diesel engine, the speed of the engine may vary (probably malfunction of the governor). Though a governor is provided to control the speed of the diesel engine, the speed might go out of control, damaging the engine. Thus, for this reason over speed trips are used	Random Failure	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage.	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Propulsion	Critical	Remote	Medium	Runzhi Wang, Xuemin Li, Jiguang Zhang, Jian Zhang, Wenhui Li, Yufei Liu, Wenjie Fu, & Xiuzhen Ma, 2018. *Speed Control for a Marine Diesel Engine Based on the Combined Linear-Nonlinear Active Disturbance Rejection Control* . Hindawi Journal.
				The engine starts to runaway. This is common in old diesel engines. A runaway is a condition in which the engine gets fuel from an unintended source and rotates faster than its governed speed. This condition caused of Malfunction of the fuel oil pumps	Random Failure	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage.	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Propulsion	Critical	Remote	Medium	
	1.3 Transmit less than 1000 RPM rotation during operation	1.12	Crankshaft cracked	All diesel crankshafts are heat treated. This heat treating is done to increase wear resistance, improve fatigue and obtain a high surface hardness. Because of this process the crankshaft is extremely hard but also brittle. When an engine has a bearing failure, the excessive clearance can cause the crank to have a "jump rope" effect inside the engine. The crankshaft can bend severely or even break in some cases.	Wear Out Failure	The causes damage to the crank effecting to housing bores of the connecting rods and mains in the engine block. The broken cranks can pull on the housing bores of the connecting rods and engine block. Also, main caps can become loose in the registers causing misalignment.	Engine Stop	Propulsion	Catastrophic	Improbable	Medium	Lucjan Witek, Feliks Stachowicz, & Arkadiusz Zaleski, 2017. Failure Investigation of the Crankshaft of Diesel Engine. Portugal: 2nd International Conference on Structural Integrity.
	1.4 No transmission of power to the propulsion shafting	1.13	Breakage Timing belt	The excessive load can begin to crack under stress. As the material cracks, it's a higher risk for snapping and breaking in the engine.	Random Failure	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Propulsion	Catastrophic	Occasional	High	Harshal Pandya, Dr. Dipesh Kundaliya, Dr. Jignasa Mehta, & Mr. Jayanti Gorasiya, 2016. A Review: Identify Reasons of Timing Belit Failure Analysis with Corrective & Preventive Measures. International Journal of Engineering Development and Research (IJEDR).
				The timing belt is usually made from a rubber material with teeth on one side to control the gears, pulleys, and components in the engine. With the heat and friction inside the engine, the rubber teeth may wear down and no longer be able to grip the gears. This often results in a slip of the timing belt and potential damage to the engine.	Wear Out Failure	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Propulsion	Catastrophic	Occasional	High	

<u>Appendix 5</u>

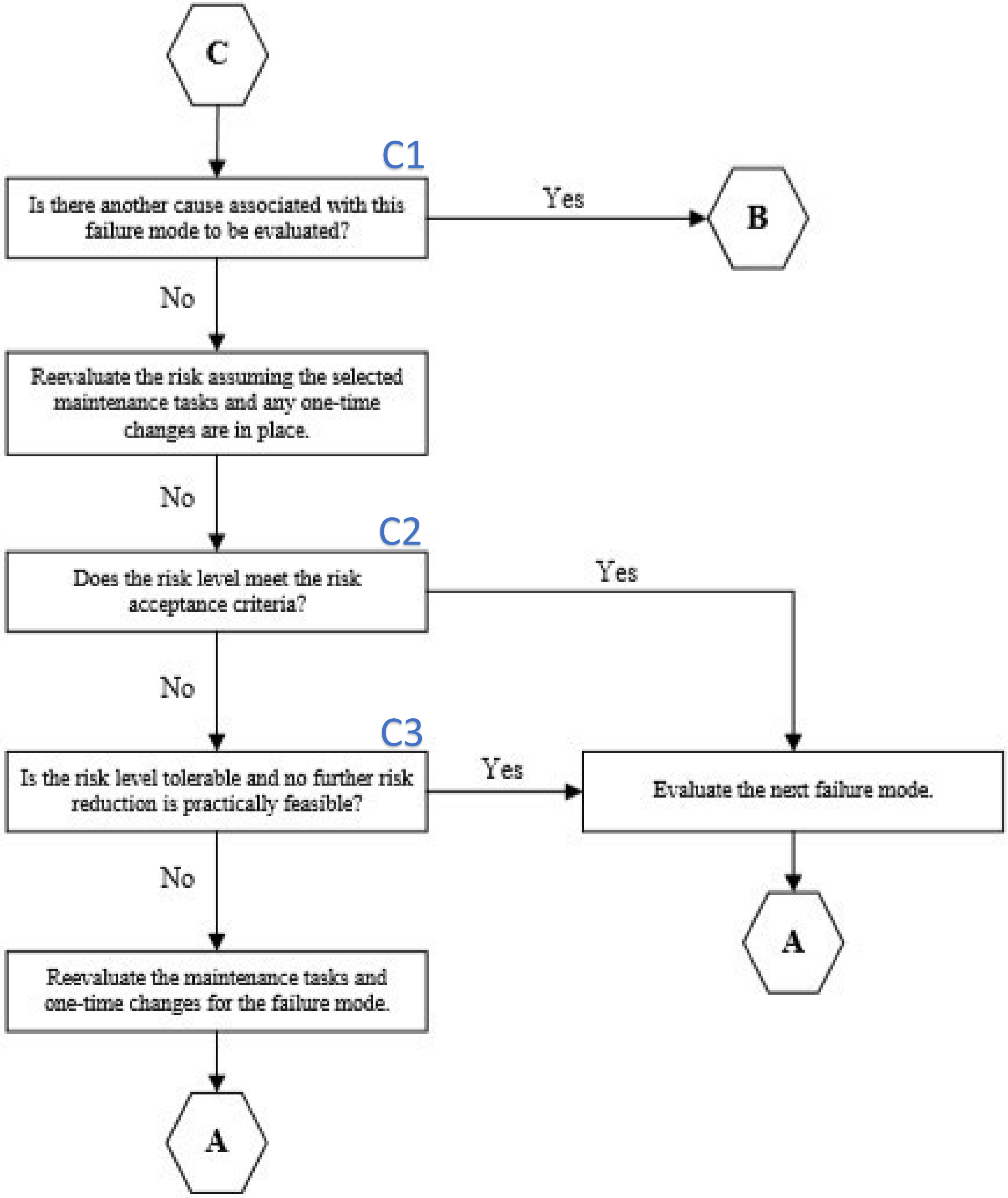
FMECA Worksheet

Function	Function Failure	Item No.	Failure Mode	Causes	Failure Characteristics	Risk		Matrix Category Consequence	Severity	Current Likelihood	Curent Risk	Remark
						Local Effects	End Effects					
		1.14	Engine failed to start	It caused by the air starting system problem. It can be air receiver capacity is not optimal, compressor worn out or compressor pressure is less than from specification technical data, or piping compressed air system is leaking	Wear Out Failure	Cannot starting the engine	Engine Stop	Propulsion	Catastrophic	Occasional	High	NAVEDTRA 14050a, 2016. Chapter 4 Engine Troubleshooting.
		1.15	Contamintaed lube oil and fuel oil	When unburned diesel fuel makes its way past the rings and into the engine oil in the crankcase, fuel contamination, or fuel dilution, results. Fuel dilution can decrease oil viscosity and lubricity even at very low levels, increasing both bearing wear and the potential for bearing failure.	Random Failure	Fuel contamination is a serious issue that makes early detection vital to maintaining component health. As diesel fuel lowers oil viscosity, it reduces the corrosion protection of its additives and accelerates component wear.	Extremely can result in a crankcase explosion.	Propulsion	Critical	Remote	Medium	Bureau Veritas, 2019. *Identifying Engine Oil Contamination* . Bureu Veritas Website.

RCM Task Selection Flow Diagram



RCM Task Selection Flow Diagram



Appendix 6

FMECA LTA Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristi	Hidden /Evident	Effects		Risk Characterization			RCM LTA Task Selection												
						Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
1. To Transmit 2100 BHP at 1000 RPM of power	1.1 Transmits less than 1565 kW of power to the propulsion shafting	1.1	Clogged fuel filter	Wear Out Failure	Evident	If there is a problem caused by a clogged fuel filter, then it will show up as a fuel injection system error. Because of the fuel to the fuel injector is restricted.	Not changing the fuel filter regularly can lead to engine performance issues and start difficulties. These issues can usually be remedied by fitting a new filter.	Critical	Remote	Medium	N	-	N	Y	-	N	Y	-	-	-	-	-	Specify combination tasks at 1/2 the P-F interval and the life limit
		1.2	Low Output fuel from Fuel Injector	Wear Out Failure	Evident	If a clogged fuel injector continually disperses fuel to the engine, a time will come when it misses the fuel supply completely and the engine will misfire. The misfire will make the engine can quickly overheat and pre-ignite the fuel mixture	It leads to engine performance and starting issues	Critical	Remote	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
		1.3	Leakage Crankshaft Seals	Wear Out Failure	Evident	The crank seal purpose in keeping the oil that is constantly being used and tossed by the crankshaft as it rotates from leaking out of the engine's crankcase. When they fail they can cause leaks which can make a mess, even put the engine damage. Such as broken crankshaft because out of lubricating oil.	The part of the engine would be worn out before it should be and Engine oveheat	Major	Occasional	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 6

FMECA LTA Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristi	Hidden /Evident	Effects		Risk Characterization			RCM LTA Task Selection												
						Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
		1.4	Cracked Piston	Wear-out Failure	Evident	The cracked piston causing lose compression	Low compression caused low power	Critical	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval
		1.5	Demaged Piston Ring	Wear-out Failure	Evident	The damaged piston ring can effect is excessive oil consumption and low power for acceleration	For the worse, it can be an overall loss of power	Critical	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval
		1.6	Breakage air inlet valve	Wear Out Failure	Evident	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Critical	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval
		1.7	Piston Slap	Wear Out Failure	Evident	Piston is commonly heard when the engine is cold and often gets louder when the vehicle accelerates. When a piston slaps againts the cylinder wall, the result is a hollow, bell-like sound.	It can lead to poor compression and power loss.	Critical	Improbable	Low	Y	Y	-	-	-	-	-	-	-	-	-	-	Specify run-to failure
		1.8	Breakage Exhaust Valve	Wear Out Failure	Evident	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Critical	Occasional	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

<u>Appendix 6</u>

FMECA LTA Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristi	Hidden /Evident	Effects		Risk Characterization			RCM LTA Task Selection												
						Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
		1.9	Breakage cylinder head	Wear Out Failure	Evident	A number of issues can arise from a cracked cylinder head. Coolant can enter the cylinders and engine block through the crack. This can contaminate the oil, causing other major engine problems. It could also cause pitting and damage to the engine block. If the coolant enters the cylinder itself, it is often burned off in the exhaust, while damaging the cylinders.	Engine Stop	Catastrophic	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval
		1. 10	Breakage cylinder liner	Wear Out Failure	Evident	The effect will be low firing or compression pressure and rapid wear of piston rings	Power Loss	Critical	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval
	1.2 Transmits more than 1565 kW of power to the propulsion shafting	1.11	Overspeed	Random Failure	Evident	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage.	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Catastrophic	Improbable	Medium	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the tasks at the appropriate interval to achive a tolerable risk

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 6

FMECA LTA Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristi	Hidden /Evident	Effects		Risk Characterization			RCM LTA Task Selection												
						Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
				Random Failure	Evident	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Catastrophic	Improbable	Medium	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the tasks at the appropriate interval to achive a tolerable risk
	1.3 Transmit less than 1000 RPM rotation during operation	1.12	Crankshaft cracked	Wear Out Failure	Evident	The causes damage to the crank effecting to housing bores of the connecting rods and mains in the engine block. The broken cranks can pull on the housing bores of the connecting rods and engine block. Also, main caps can	Engine Stop	Catastrophic	Improbable	Medium	N	-	N	Y	-	Y	-	-	-	-	-	-	Specify planned maintenance at the appropriate life limit
	1.4 No transmission of power to the propulsion shafting	1.13	Breakage Timing belt	Random Failure	Evident	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Catastrophic	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the tasks at the appropriate interval to achive a tolerable risk
				Wear Out Failure	Evident	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Catastrophic	Occasional	High	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the tasks at the appropriate interval to achive a tolerable risk
		1.14	Engine failed to start	Wear Out Failure	Evident	Cannot starting the engine	Engine Stop	Catastrophic	Remote	Medium	Y	N	N	N	-	-	-	-	Y	-	-	-	Specify the tasks at the appropriate interval to achive a tolerable risk

Risk Characterization

S: Severity **CL: Current Likelihood** **CR: Current Risk**

Appendix 6

FMECA LTA Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristi	Hidden /Evident	Effects		Risk Characterization			RCM LTA Task Selection												
						Local	End	S	CL	CR	A1	A2	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	Result
		1.15	Contamintaed lube oil and fuel oil	Random Failure	Evident	Fuel contamination is a serious issue that makes early detection vital to maintaining component health. As diesel fuel lowers oil viscosity, it reduces the corrosion protection of its additives and accelerates component wear.	Extremely can result in a crankcase explosion.	Critical	Remote	Medium	N	-	Y	-	-	-	-	-	-	-	-	-	Specify condition-monitoring task at 1/2 the P-F interval

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 7

Maintenance Task Selection Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristics	Hidden /Evident	Effects		Risk Characterization			Task Selection		
						Local	End	S	CL	CR	Proposed Action	PL	PR
1. To Transmit 2100 BHP at 1000 RPM of power	1.1 Transmits less than 1565 kW of power to the propulsion shafting	1.1	Clogged fuel filter	Wear Out Failure	Evident	If there is a problem caused by a clogged fuel filter, then it will show up as a fuel injection system error. Because of the fuel to the fuel injector is restricted.	Not changing the fuel filter regularly can lead to engine performance issues and start difficulties. These issues can usually be remedied by fitting a new filter.	Critical	Remote	Medium	•Check pressure drop indicators and change filter catridges if high pressure drop is indicated •Replace fuel oil filter catridges •Check the type of fuel used it must be in accordance with the characteristics of the engine and specifications [bunkering]	Improbable	Low
		1.2	Low Output fuel from Fuel Injector	Wear Out Failure	Evident	If a clogged fuel injector continually disperses fuel to the engine, a time will come when it misses the fuel supply completely and the engine will misfire. The misfire will make the engine can quickly overheat and pre-ignite the fuel mixture	It leads to engine performance and starting issues	Critical	Remote	Medium	•Inspect injector fuel •Check nozzle condition in a test pump (replace the nozzle, if necessary) •Overhaul of injection pump	Improbable	Low
		1.3	Leakage Crankshaft Seals	Wear Out Failure	Evident	The crank seal purpose in keeping the oil that is constantly being used and tossed by the crankshaft as it rotates from leaking out of the engine's crankcase. When they fail they can cause leaks which can make a mess, even put the engine damage. Such as broken crankshaft because out of lubricating oil.	The part of the engine would be worn out before it should be and Engine oveheat	Major	Occasional	Medium	Seals Periodic replacement, If the seals broke once it must be replaced it can't be maintained	Remote	Low

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

<u>Appendix 7</u>

Maintenance Task Selection Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristics	Hidden /Evident	Effects		Risk Characterization			Task Selection		
						Local	End	S	CL	CR	Proposed Action	PL	PR
		1.4	Cracked Piston	Wear-out Failure	Evident	The cracked piston causing lose compression	Low compression caused low power	Critical	Remote	Medium	Inspect, pull inspect and clean, check the height of the ring grooves, check the retainer rings of the gudgeon pins, replace complete set of piston rings, and note the running-in program	Improbable	Low
		1.5	Demaged Piston Ring	Wear-out Failure	Evident	The damaged piston ring can effect is excessive oil consumption and low power for acceleration	For the worse, it can be an overall loss of power	Critical	Remote	Medium	Inspect, pull inspect and clean, check the height of the ring grooves, check the retainer rings of the gudgeon pins, replace complete set of piston rings, and note the running-in program	Improbable	Low
		1.6	Breakage air inlet valve	Wear Out Failure	Evident	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Critical	Remote	Medium	•Check valve clearance •Check valve condition •Check nuts of the flange connections. Tighten loose nuts •Check valve mechanism bearing, check tappels and rocker arms	Improbable	Low
		1.7	Piston Slap	Wear Out Failure	Evident	Piston is commonly heard when the engine is cold and often gets louder when the vehicle accelerates. When a piston slaps againts the cylinder wall, the result is a hollow, bell-like sound.	It can lead to poor compression and power loss.	Critical	Improbable	Low	Correction requires either (it depends on the causes): •Replacing the pistons •Reboring the cylinder •Replacing or realigning the rods •Replacing the bearings	-	-
		1.8	Breakage Exhaust Valve	Wear Out Failure	Evident	This could cause compression issues. When a valve is burned, it can lose material and even have large holes which leak out gases and reduce compression.	It can lead to poor combustion and power loss.	Critical	Occasional	Medium	•Check valve clearance •Check valve condition •Check nuts of the flange connections. Tighten loose nuts •Check valve mechanism bearing, check tappels and rocker arms	Remote	Medium

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 7

Maintenance Task Selection Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristics	Hidden /Evident	Effects		Risk Characterization			Task Selection		
						Local	End	S	CL	CR	Proposed Action	PL	PR
		1.9	Breakage cylinder head	Wear Out Failure	Evident	A number of issues can arise from a cracked cylinder head. Coolant can enter the cylinders and engine block through the crack. This can contaminate the oil, causing other major engine problems. It could also cause pitting and damage to the engine block. If the coolant enters the cylinder itself, it is often burned off in the exhaust, while damaging the cylinders	Engine Stop	Catastrophic	Remote	Medium	•Visual inspection of the cylinder head and cylinder liner •Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion	Improbable	Medium
		1. 10	Breakage cylinder liner	Wear Out Failure	Evident	The effect will be low firing or compression pressure and rapid wear of piston rings	Power Loss	Critical	Remote	Medium	•Visual inspection of the cylinder head and cylinder liner •Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion	Improbable	Low
	1.2 Transmits more than 1565 kW of power to the propulsion shafting	1.11	Overspeed	Random Failure	Evident	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage.	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Catastrophic	Improbable	Medium	•Check oil level in governor •Change oil in governor •Check functions of overspeed trip •Inspect the governor driving gear. Replace if necessary •Check the governor drive bearing and clearance •Check the function of governor. Replace worn parts •General overhaul of overspeed trip device. Check function and tripping speed	Improbable	Medium

Risk Characterization
S: Severity
CL: Current Likelihood
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Appendix 7

Maintenance Task Selection Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristics	Hidden /Evident	Effects		Risk Characterization			Task Selection		
						Local	End	S	CL	CR	Proposed Action	PL	PR
				Random Failure	Evident	Overspeed is any speed beyond the operating range specified by the engine manufacturer. Engine Overspeed may result in costly damage	Overspeed leads to serious damage, not only to the engine itself but also to generators and gears.	Catastrophic	Improbable	Medium	•Checking of gauges (replace the faulty one) •Check functions of overspeed trip •General overhaul of overspeed trip device. Check function and tripping speed	Improbable	Medium
	1.3 Transmit less than 1000 RPM rotation during operation	1.12	Crankshaft cracked	Wear Out Failure		The causes damage to the crank effecting to housing bores of the connecting rods and mains in the engine block. The broken cranks can pull on the housing bores of the connecting rods and engine block. Also, main caps can become loose in the registers causing misalignment.	Engine Stop	Catastrophic	Improbable	Medium	•Check crankshaft alignment •Inspect balancing bearing. Take one bush out. If in bad condition, check the other bushes. Replace if necessary •Check thrust bearing clearance & axial clearance •Inspect the big end and main bearing, measure the crankpin diameter and ovality •Inspect the crankshaft bearing surfaces	Improbable	Medium
	1.4 No transmission of power to the propulsion shafting	1.13	Breakage Timing belt	Random Failure	Evident	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Catastrophic	Occasional	High	Replace Timing Belt	Remote	Medium
				Wear Out Failure	Evident	It leads to Unproperly synchronizes the camshaft to the crankshaft position	Engine Stop	Catastrophic	Occasional	High	Replace Timing Belt	Remote	Medium

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 7

Maintenance Task Selection Worksheet

Function	Function Failure	Item No.	Failure Mode	Failure Characteristics	Hidden /Evident	Effects		Risk Characterization			Task Selection		
						Local	End	S	CL	CR	Proposed Action	PL	PR
		1.14	Engine failed to start	Wear Out Failure	Evident	Cannot starting the engine	Engine Stop	Catastrophic	Remote	Medium	•Test start process •Air compressor, Inspect LO level inside crankcase daily. Clean overhaul High Pressure & Low Pressure valves •Air Receiver Internal & Saftey Valve check, Clean & Inspect internal surface and safety valve overhaul and testing	Remote	Medium
		1.15	Contamintaed lube oil and fuel oil	Random Failure	Evident	Fuel contamination is a serious issue that makes early detection vital to maintaining component health. As diesel fuel lowers oil viscosity, it reduces the corrosion protection of its additives and accelerates component wear.	Extremely can result in a crankcase explosion.	Critical	Remote	Medium	•Pressure testing the fuel delivery components •Check porosity in the cylinder head casting, failed injector O-ring seals, leaking fuel jumper pipes, and cracked cylinder head galleries	Improbable	Low

Risk Characterization
S: Severity
CL: Current Likelihood
CR: Current Risk

Appendix 8

Summary of Maintenance

Maintenance catergory	: Category A						
Functional Group	: Propulsion						
System	: Basics Main Engine						
Equipment Item	: Main Engine						
Component	: Part of Internal Combustion Engine						
Task	**Task Type**	**Item No.**	**Risk**		**Frequency (months)**	**Procedure No. or Class Reference**	**Comments**
			Current	**Projected**			
Test start process	PM	1.3	Medium	Medium	Weekly		by on board personnel
Check pressure drop indicators and change filter catridges if high pressure drop is indicated	CM	1.4	Medium	Medium	Weekly		by on board personnel
Replace fuel oil filter catridges	PM	1.4	Medium	Low	24		by on board personnel
Check the type of fuel used it must be in accordance with the characteristics of the engine and specifications	CM	1.4	Medium	Low	bunkering		by on board personnel
Check oil level in governor	CM	1.12	Medium	Medium	Weekly		by on board personnel
Change oil in governor	PM	1.12	Medium	Medium	6		by on board personnel

Appendix 8

Summary of Maitenance

Maintenance catergory	: Category B
Functional Group	: Propulsion
System	: Basics Main Engine
Equipment Item	: Main Engine
Component	: Internal

Task	Task Type	Item No.	Risk		Frequency (months)	Procedure No. or Class Reference	Comments
			Current	Projected			
Replace Timing Belt	PM	1.1, 1.2	High	Medium	36		Must be undertaken alongside by vendors
Air compressor, Inspect LO level inside crankcase daily. Clean overhaul HP & LP valves	PM	1.3	Medium	Medium	24		
Air Receiver Internal & Saftey Valve check, Clean & Inspect internal surface and safety valve overhaul and testing	PM	1.3	Medium	Medium	24		
Inspect injector fuel	PM	1.5	Medium	Low	24		
Check nozzle condition in a test pump (replace the nozzle, if necessary)	PM	1.5	Medium	Low	24	ABS Rules (Vessel Systems and Machinery) 4-2-1/Table 2	
Overhaul of injection pump	PM	1.5	Medium	Low	48	ABS Rules (Vessel Systems and Machinery) 4-2-1/Table 2	
Seals Periodic replacement, If the seals broke once it must be replaced it can't be maintained	PM	1.6	Medium	Low	48		

Appendix 8

Summary of Maitenance

Maintenance catergory	: Category B
Functional Group	: Propulsion
System	: Basics Main Engine
Equipment Item	: Main Engine
Component	: Internal

Task	Task Type	Item No.	Risk		Frequency (months)	Procedure No. or Class Reference	Comments
			Current	Projected			
Replacing the pistons if necessary	RTF	1.7	Low	Low	36		Must be undertaken alongside by vendors
Replacing the cylinder if necessary	RTF	1.7	Low	Low	36		
Replacing or realigning the rods if necessary	RTF	1.7	Low	Low	36		
Replacing the bearings if necessary	RTF	1.7	Low	Low	36		
Inspect, pull inspect and clean, check the height of the ring grooves, check the retainer rings of the gudgeon pins, replace complete set of piston rings, and note the running-in program	PM	1.8, 1.9	Medium	Low	48		
Check nuts of the flange connections. Tighten loose nuts	CM	1.10, 1.11	Medium	Low	24	ABS Rules (Vessel Systems and Machinery) 4-2-1/5.7	
Check valve mechanism bearing, check tappels and rocker arms	PM	1.10, 1.11	Medium	Low	48		
Check air inlet valve clearance	CM	1. 10	Medium	Low	24		
Check air inlet valve condition	CM	1. 10	Medium	Low	24		

Appendix 8

Summary of Maitenance

Maintenance catergory	: Category B
Functional Group	: Propulsion
System	: Basics Main Engine
Equipment Item	: Main Engine
Component	: Cylinder

Task	Task Type	Item No.	Risk		Frequency (months)	Procedure No. or Class Reference	Comments
			Current	Projected			
Check exhaust valve clearance	CM	1.11	Medium	Medium	24		Must be undertaken alongside by vendors
Check exhaust valve condition	CM	1.11	Medium	Medium	24		
Visual inspection of the cylinder head and cylinder liner	CM	1.12	Medium	Medium	36		
Check functions of overspeed trip	CM	1.12	Medium	Medium	24		
Inspect the governor driving gear. Replace if necessary	PM	1.12	Medium	Medium	24		
Check the function of governor. Replace worn parts	PM	1.12	Medium	Medium	48		
Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion	CM	1.12	Medium	Low	48		
Check the governor drive bearing and clearance	CM	1.12	Medium	Medium	36		

Appendix 8

Summary of Maitenance

Maintenance catergory	: Category B
Functional Group	: Propulsion
System	: Basics Main Engine
Equipment Item	: Main Engine
Component	: Cylinder

Task	Task Type	Item No.	Risk		Frequency (months)	Procedure No. or Class Reference	Comments
			Current	Projected			
Visual inspection of the cylinder head and cylinder liner	CM	1.13	Medium	Low	36		Must be undertaken alongside by vendors
Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion	CM	1.13	Medium	Low	48		
General overhaul of overspeed trip device. Check function and tripping speed	PM	1.14	Medium	Medium	48		
Check crankshaft alignment	PM	1.14	Medium	Medium	48		
Inspect balancing bearing. Take one bush out. If in bad condition, check the other bushes. Replace if necessary	FF	1.14	Medium	Medium	24		
Check thrust bearing clearance & axial clearance	PM	1.14	Medium	Medium	24		

Appendix 8

Summary of Maitenance

Maintenance catergory	: Category B						
Functional Group	: Propulsion						
System	: Basics Main Engine						
Equipment Item	: Main Engine						
Component	: Cylinder						
Task	**Task Type**	**Item No.**	**Risk**		**Frequency (months)**	**Procedure No. or Class Reference**	**Comments**
			Current	**Projected**			
Inspect the big end and main bearing, measure the crankpin diameter and ovality	PM	1.14	Medium	Medium	48		Must be undertaken alongside by vendors
Inspect the crankshaft bearing surfaces	PM	1.14	Medium	Medium	48		Must be undertaken alongside by vendors
Pressure testing the fuel delivery components	CM	1.15	Medium	Low	36		
Check porosity in the cylinder head casting, failed injector O-ring seals, leaking fuel jumper pipes, and cracked cylinder head galleries	CM	1.15	Medium	Low	36		

Appendix 9

Work Package

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
Weekly	Mechanic	
Test start process		Category A
Check pressure drop indicators and change filter catridges if high pressure drop is indicated		Category A
Check oil level in governor		Category A

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
6 Months	Mechanic	
Change oil in governor		Category A

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
24 Months	Mechanic	
Replace fuel oil filter catridges		Category A
Inspect injector fuel		Category B
Check nozzle condition in a test pump (replace the nozzle, if necessary)		Category B
Check nuts of the flange connections. Tighten loose nuts		Category B
Check functions of overspeed trip		Category B
Air compressor, Inspect LO level inside crankcase daily. Clean overhaul HP & LP valves		Category B

Appendix 9

Work Package

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
24 Months	Mechanic	
Air Receiver Internal & Saftey Valve check, Clean & Inspect internal surface and safety valve overhaul and testing		Category B
Speed Instrument: Checking of gauges (replace the faulty one)		Category B
Check air inlet valve clearance		Category B
Check air inlet valve condition		Category B
Inspect the governor driving gear. Replace if necessary		Category B
Check exhaust valve clearance		Category B
Inspect balancing bearing. Take one bush out. If in bad condition, check the other bushes. Replace if necessary		Category B
Check thrust bearing clearance & axial clearance		Category B
Check exhaust valve condition		Category B

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
36 Months	Mechanic	
Replace Timing Belt		Category B
Replacing the pistons if necessary		Category B
Replacing the cylinder if necessary		Category B
Replacing or realigning the rods if necessary		Category B
Replacing the bearings if necessary		Category B
Visual inspection of the cylinder head and cylinder liner		Category B
Check the governor drive bearing and clearance		Category B

Appendix 9

Work Package

Maintenance Schedule		
Main Engine		
Interval	**Done by**	**Category**
48 Months	Mechanic	
Overhaul of injection pump		Category B
Seals Periodic replacement, If the seals broke once it must be replaced it can't be maintained		Category B
Check valve mechanism bearing, check tappels and rocker arms		Category B
Inspect, pull inspect and clean, check the height of the ring grooves, check the retainer rings of the gudgeon pins, replace complete set of piston rings, and note the running-in program		Category B
Check the function of governor. Replace worn parts		Category B
Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion		Category B
Check the condition and cleaning of cylinder heads and cylinder liners for combustion residues, dirt, scale and corrosion		Category B
General overhaul of overspeed trip device. Check function and tripping speed		Category B
Check crankshaft alignment		Category B
Inspect the big end and main bearing, measure the crankpin diameter and ovality		Category B
Inspect the crankshaft bearing surfaces		Category B
Pressure testing the fuel delivery components		Category B
Check porosity in the cylinder head casting, failed injector O-ring seals, leaking fuel jumper pipes, and cracked cylinder head galleries		Category B

Appendix 10

Basic Maintenance

SHIP'S PLANNED MAINTENANCE SCHEDULE
ENGINE DEPARTMENT

Vessel Name: Tugboat X
Period of time: January-August 2019
Type of Engine: Wartsila 9L20

Symbol: S = Schedule Maintenance
C = Completed Maintenance

PMS No.	Unit/System	Description of Work Done	Interval		Next Due 2019							
			Months	Hours	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug
	Current Total Running Hours		17584 Hours									
1	**Main Engine**											
1.1	Start Process	Test start	Weekly	Weekly	C	C	C	C	C	C	C	C
1.2	Fuel and lub Oil filter	Check pressure drop indicators, Change filter catridges if high pressure drop is indicated	Weekly	50	C	C	C	C	C	C	C	C
1.3	Gauges and Indicators	Take readings	Weekly	50	C	C	C	C	C	C	C	C
1.4	Injection and fuel system	Check leak fuel quantity	Weekly	50	C	C	C	C	C	C	C	C
1.5	Main bearing	Check lightening of main bearing screw	Weekly	50	C	C	C	C	C	C	C	C
1.6	Valve mechanism	Check valve clearance	Weekly	50	C	C	C	C	C	C	C	C
1.7	Cylinder pressure	Check cylider pressure, record firing pressures all cylinder	2	500	C		C		C		C	
1.8	Fuel filter	Replace fuel oil filter catridges	3	1000	C			C			C	
1.9	Valve	Check of valve condition	3	1000	C			C			C	

Appendix 10

Basic Maintenance

PMS No.	Unit/System	Description of Work Done	Interval		Next Due 2019							
			Months	Hours	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug
1. 10	Injection valve	Inspect injection valve	6	2000	C						C	
1.11	Overspeed trip device	Check function of over speed trip	6	2000	C						C	
1.12	Camshaft	Inspect contact faces of camshaft	12	4000	C							
1.13	Crankshaft	Check crankshaft allignment	12	4000	C							
1.14	Cylinder Liners	Inspect jacket water spaces.Pull ones cylinder liners if deposits are thicker than 1mm, clean all liners and engine block water space	12	4000	C							
1.15	Exhaust manifold	Check nuts of the flange connection. Tighten loose nuts	12	4000	C							
1.16	Nozzles	Check the nozzle condition in a test pump (replace the nozzle by new ones)	12	4000	C							
1.17	Air compressor	Inspect LO level inside crankscase daily. Clean, overhaul HP & LP valves	12	2000-3000	C							
1.18	Balancing shaft	Inspect balancing shaft bearing. Take one bush out, If in bad condition, replace if necessary	24	8000	S							
1.19	Camshaft driving gear	Inspect and check clearance and backlash. Replace part if necessary	24	8000	S							

Appendix 10

Basic Maintenance

PMS No.	Unit/System	Description of Work Done	Interval		Next Due 2019							
			Months	Hours	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug
1. 20	Crankshaft	Check thrust bearing clearances & axial clearance	24	8000	S							
1.21	Cylinder heads	Overhaul of cylinder head	24	8000	S							
1.22	Cylinder liner	Inspect, measure bore, replace liner if wear limits are exceeded. Hone liners. Check the antipolishing ring if provided. Turn the ring up side down if worn	24	8000	S							
1.23	Cylinder liner	Inspect cylinder liner water side	24	8000	S							
1.24	Main bearing	Inspect the bearing shells. Replace if necessary	24	8000	S							
1.25	Piston, piston rings	Pull inspect and clean. Check the height of the ring grooves. Check the retainer ring of the gudgeon pins. Replace complete set of piston rings. Note the running-in program	24	8000	S							
1.26	Camshaft	Inspect camshaft bearing. Replace if necessary	48	16000	S							
1.27	Crankshaft	Inspect the big end and main bearing, measure the crankpin diameter and ovality	48	16000	S							

Appendix 10

Basic Maintenance

PMS No.	Unit/System	Description of Work Done	Interval		Next Due 2019							
			Months	Hours	Jan	Feb	Mar	Apr	Mei	Jun	Jul	Aug
1.28	Injection pumps	Overhaul of injection pumps	48	16000	S							
1.29	Valve mechanism	Check valve mecanism bearing, check tappets and rocker arms	48	16000	S							
1. 30	Crankshaft	Inspect the crankshaft bearing surfaces	80	24000	S							
1.31	Overspeed trip device	General overhaul of overspeed trip devices. Check function and tripping speed	80	24000	S							
1.32	Engine	General overhaul	320	64000	S							
1.33	Air reciever internal & Safety Valve check	Check & Inspect surfaces, safety valve overhaul and testing	60	000-1000	S							

AUTHOR BIOGRAPHY

The author was born in Medan, North Sumatera on March 23, 1999, named Madina Nur Pratiwi. She is the first child of Juprianto and Euis Budiarti Afandi. She starts her educational at SDN 03 Pg Pondok Kelapa, Jakarta (2004 - 2010), SMPN 255 Jakarta (2010-2013), SMAN 12 Jakarta (2013-2016). After graduated from high school, the author was accepted at the Department of Marine Engineering, Faculty of Marine Technology, Sepuluh November Institute of Technology through the SNMPTN admission in 2016. During the study period, the writer was active in various activities and organizations. Among them are the HIMASISKAL, ITS Marine Solar Boat Team, BEM ITS, and voluntary activities. The author decides to take the field of Maintenance System for the Bachelor Thesis using RCM Method. The author can be contacted via the following email: madinannurpratiwi@gmail.com

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