BACHELOR THESIS & COLLOQUIUM – ME1841038

ASSESSMENT OF A RELEVANT OPERATIONAL SYSTEM ON BOARD A SHIP BY UTILIZATION OF DIFFERENT MAINTENANCE STRATEGIES

SAFITRI AULIA RAMADHANY WIDODO
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DOUBLE DEGREE PROGRAM
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SKRIPSI - ME 1841038

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202

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APPROVAL SHEET

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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

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Asked To Meet One Of The Conditions

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on

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AGUSTUS, 2020

DECLARATION OF HONOR

I hereby who signed below declare that:
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Warnemünde, August 2020

Safitri Aulia Ramadhany Widodo

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ASSESSMENT OF A RELEVANT OPERATIONAL SYSTEM ON BOARD A SHIP BY UTILIZATION OF DIFFERENT MAINTENANCE STARTEGIES

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ABSTRACT

During ship operation, an accident may occur because of a lack of maintenance on the equipment. Maintenance on the piping system is essential for safety personnel and the environment. One of the systems on the ship as an emergency system is bilge water system. Bilge water system consists of two, bilge system and oily bilge system. Oily bilge water system is for taking the oil from water mixture. The oil containment in water mixture minimal under 15 ppm to prevent harm to the environment. Maintenance strategies are needed to avoid the risk of failure. To identify failure mode, there are Failure Mode and Effect Analysis (FMEA) and Hazard of Operation Study (HAZOP) that designed to identify potential failure modes of equipment. Every risk assessment has different advantages and disadvantages.

Based on this thesis's result, there are 24 planning maintenance tasks and a schedule for the bilge water system. The percentage of maintenance strategies for each type of failure mode is Preventive Maintenance (PM) is 38%, Corrective Maintenance (CM) 33%, and Failure Finding (FF) 29%. Besides doing maintenance strategies, calculation of the reliability and failure rate of equipment using ReliaSoft Weibull software also important. It showed that equipment reliability could decrease, and the failure rate of equipment can increase as time went by.

Key words - Maintenance Startegies, Bilge Water System, Oily Bilge Water System, FMEA, HAZOP, Reliability, Failure Rate, Weibull

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PENILAIAN SISTEM OPERASIONAL YANG RELEVAN PADA KAPAL DENGAN MENGGUNAKAN STRATEGI PEMELIHARAAN YANG BERBEDA

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ABSTRAK

Selama pengoperasian kapal, kecelakaan dapat terjadi karena kurangnya perawatan pada peralatan. Perawatan pada sistem perpipaan sangat penting untuk personel keselamatan dan lingkungan. Salah satu sistem di kapal sebagai sistem darurat adalah sistem bilge water. Sistem air bilge terdiri dari dua yaitu sistem lambung kapal dan sistem lambung kapal berminyak. Sistem lambung kapal berminyak untuk mengambil minyak dari campuran air. Penahanan minyak dalam campuran air minimal di bawah 15 ppm untuk mencegah kerusakan lingkungan. Strategi pemeliharaan diperlukan untuk menghindari risiko kegagalan. Untuk mengidentifikasi mode kegagalan, terdapat Failure Mode and Effect Analysis (FMEA) dan Hazard of Operation Study (HAZOP) yang dirancang untuk mengidentifikasi potensi mode kegagalan peralatan. Setiap penilaian risiko memiliki kelebihan dan kekurangan yang berbeda.

Berdasarkan hasil skripsi ini, terdapat 24 tugas perencanaan pemeliharaan dan penjadwalan sistem bilge water. Persentase strategi perawatan untuk setiap jenis mode kegagalan adalah Preventive Maintenance (PM) sebesar 38%, Corrective Maintenance (CM) 33%, dan Failure Finding (FF) 29%. Selain melakukan strategi perawatan, perhitungan tingkat kehandalan dan kegagalan peralatan menggunakan software ReliaSoft Weibull juga penting. Hal tersebut menunjukkan bahwa keandalan peralatan dapat menurun, dan tingkat kegagalan peralatan dapat meningkat seiring berjalannya waktu.

Key words - Strategi Pemeliharaan, Sistem Bilga, Sistem Bilga Berminyak, FMEA, HAZOP, Keandalan, Tingkat Kegagalan, Weibull

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PREFACE

Praises to God, for the opportunity, and strength to finish this bachelor thesis with the tittle "ASSESSMENT OF A RELEVANT OPERATIONAL SYSTEM ON BOARD A SHIP BY UTILIZATION OF DIFFERENT MAINTENANCE STARTEGIES" in order to fulfill the requirements to get a Bachelor of Engineering degree in the Department of Marine Engineering, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember Surabaya.

The author would like to express her gratitude to all those who helped, supported, and offered encouragement on this bachelor thesis writing:

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2. Mr. Benny Cahyono, S.T., M.T., Ph.D, as a Head of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.
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10. All civitas academic of Marine Engineering Department, Faculty of Marine Technology, Institut Teknologi Sepuluh Nopember.

The author realizes that in writing this report there are many shortcomings, so the constructive criticisms and suggestions that the author hopes for. Hopefully this bachelor thesis can be beneficial for us.

Warnemünde, August 2020

Author

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NOMENCLATURES

ABS	American Bureau of Shipping
BKI	Biro Klasifikasi Indonesia
MARPOL	Convention for Prevention of Marine Pollution
PSC	Port State Control
OWS	Oily Water Separator
OCM	Oil Content Monitor
RPN	Risk Priority Number
FMEA	Failure Mode and Effect Analysis
HAZOP	Hazard and Operability Study
P&ID	Piping and Instrumentation Diagram
TTF	Time to Failure
AVGOF	Average Goodnes of Fit Parameter
LKV	Likelihood Value
AVPLOT	Average of Plot Fit Parameter
PM	Preventive Maintenance
CM	Condition Monitoring
FF	Failure Finding

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CHAPTER I
INTRODUCTION

1.1 Background

With ocean covers about 70.9% of the world, the shipping industry's role is important for transporting. The shipping industry is one of the important economic drives for every nation. Due to it is a large capacity, the ship can deliver more quantities compared to other transportation. Shipping companies are forced to undertake a specified transport task with reliability, safety and lowest outcome in order to compete the other companies [1]. One of the task that have to be consider is to maintain operation system of the ship Effective maintenance is essential to maximize operating time during operation service life and avoid breakdown and deterioration. Maintenance is a primary service performed on a complex system that can affect personnel and environment safety [2].

One of the system that influences operate the ship is bilge water system. Even though bilge water system constructed as an emergency system, but it is important for safety. These system are composed of pump set, valve, oil filtering equipment and other specialty equipment that make a complete system. Therefore, it is needed good startegy that secures a good balance betwwen risk and performance. In maintenance strategies, an effective and efficient maintenance managemnt will improve the performance and optimized the desired lifetime of a system. It can be processed with Failure Mode and Effect Analysis (FMEA) and Hazard of Operation Study (HAZOP) that designed to identify potential failure modes of equipment. The processed can be used guide notes from ABS rules to determine the failure rate and precise maintenance planning from each component. The result expected can be used to plan the maintenance program without distrub ship operational schedule.

1.2 Research Problem

Based on the backgrounf explanation, it can be conclued the reasearch problem are:

1. What the component of bilge water system causing the failure and what the impact of the cause?
2. What the suitable effective maintenance that can be applied to bilge water system?

1.3 Research Limitation

The limitation of the thesis is as follows:

1. The data for some qualitative analysis are coming from literature

1.4 Research Objectives

The purposes of the study is as follows:

1. Analyze component and make a concept of the regular bilge system
2. Investigate possible occurance disturbances by considering of theoretical probability of default and assess the effect
3. Choosing a proper default analysing tool
4. Compare the different analyzing tools and assess the result
5. Quantitative assessment and displaying the result

1.5 Research Benefits

The expected results is as follows:

1. Know the potential failure mode of the bilge water system.
2. Know the quantitative analysis for bilge water equipment.

CHAPTER II
LITERATURE STUDY

2.1 Bilge Water System

Bilge system is a system covering bilge area on the ship, whether it is an emergency suction system, ballast system, tanker cargo handling system, etc. As long as the system covers the bilge area of the ship, it is a bilge system. The bilge itself is the lowest part of the ship where bottom curves meet the sides (bottom platting curves up to meet side plating). The water that is collected there is also called bilge. On a ship, bilge system mainly discusses how to discharge water accumulated on bilge part to overboard. The arrangement of the bilge and ballast pumping system shall be such as prevent the possibility of water passing from the sea and from the water ballast spaces into cargo and machinery spaces, or from another compartment to another [3]

Bilge system consists of two, bilge system and oily water bilge system. Bilge system is constructed as an emergency system onboard ship to discharge water accumulated in compartments below the waterline. The chance using if the significant destruction of ship's hull due to collusion and grounding has occurred. The keyword of this system is requirement for high pump capacity. Meanwhile, oily water bilge system is not emergency system. The oily water bilge system collects oily water from engine room. Process it through separators and discharge it overboard. The chance of using this system is high (for daily basis).

2.2 Oily Water Bilge System

Before discharging the dirty water, ship produces oil and water mixture on a daily basis which needs to be separated from each other using equipment that prevents waste oil to open ocean. Tanker design features are intended to minimize oil discharge into the sea during ship operation and in case of accidents. As well as technologies and equipment that have been developed to prevent waste such as Oily Water Separator (OWS), Oil Content Meters (OCM), and etc [4].

The primary purpose of the Oily Water Separator (OWS) is to separate oil and other contaminants that could be harmful to environment. Each of OWS must able to clean bilge water under 15 ppm of oil or any other contaminants that may be found on bilge of the ships. Oil Content meters (OCM) must be active whenever OWS is being cleaned out. If the oil content is less than 15 ppm, the OCM allows the water to be discharged overboard. But if the oil content is higher than 15 ppm, the OCM will be active an alarm and will recirculate the overboard discharge water to tank on the OWS suction side.

Every ship must provide the Oil Record Book to help crew members log and keep track of oily wastewater discharge, among other things and report whenever the ship docking on the port**.** When the ship is docking, there will be port state control. Port State Control (PSC) is an inspection for an international ship to verify about condition and equipment comply with the requirement of international regulation and operate comply with the rules. With marine pollution is a significant concern, PSC look through at pollution prevention arrangement on board, such as:

- Oil Record book not properly maintained.
- Inoperable oily water separator
- Sludge overboard lines not permanently disconnected

Based on report Port State Detention from American Bureau of Shipping (ABS), MARPOL-Annex 1 is included on top 10 categories of detentions in 2017. Figure 1 shows the number percentage of detentions that happened in the port. PSC makes sure the ship complies with MARPOL Annex I standard discharge and verifies that the Oil Record book is filled out correctly by the cre

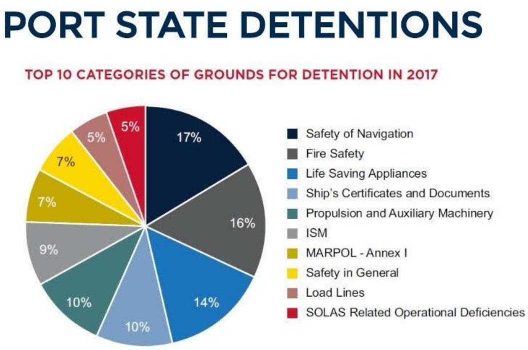

Figure 1 Port State Detentions

Source: Report Port State Detention ABS

2.3 Maintenance

Maintenance is activities that needed for physical assets, to be repaired or returned under certain conditions in specific period. This activity to ensure the reliability and availability of assets did not reduce.

2.4.1 Type of Maintenance

There are two type of maintenance that can be applied, planned and unplanned maintenance. However, there is maintenance that has to take care immediately because if not being taken care off, there will be cause severe consequences

Based on Figure 2, maintenance can be explained into several types, as follows:

1. Preventive maintenance

Preventive maintenance is planned maintenance. It is to maintain the healthy condition of equipment and prevent failure with equipment condition or periodic

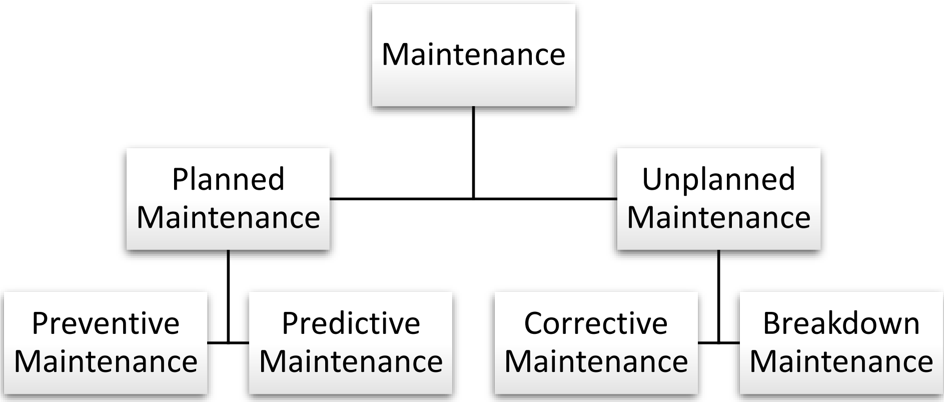

Figure 2. Types of Maintenance

Source : Corder, 1996

inspection.

Advantage:

- Increased equipment life
- Effective cost

Disadvantage:

- Required early investment
- More complex than other types of maintenance [5]

2. Predictive Maintenance

Predictive maintenance is implemented predictive system failure equipment based on condition monitoring through inspection.

Advantage:

- Downtime and cost kept at to minimum
- Reduced chance of failure and improve the reliability of equipment

Disadvantage:

- Higher cost than essential maintenance [5]

3. Corrective Maintenance

Corrective maintenance is when repair or unscheduled maintenance to replace, repair or return equipment to specific date.

Advantage:

- Minimize short-term costs
- Minimal planning time
- Only acts when a problem develop

Disadvantage:

- Higher long-term costs
- Failure can be unpredictable [5]

4. Breakdown Maintenance

Breakdown maintenance performed when equipment already fails or damaged. Breakdown maintenance can be classified as unplanned events.

Advantage:

- Reduce maintenance cost for preventive maintenance
- Narrow personnel to maintenance

Disadvantage:

- Unpredictable cost for unpredictable failures
- Difficult to find the source of problem [5]

2.4 Failure Mode and Effect Analysis (FMEA)

Failure mode and effect analysis (FMEA) is systematic approach to help engineers for indentification potential of failure mode and the consequence. FMEA is needed to analyze failure mode in the system and identified potential will be classified according to how big the failure and consequence to the system. This method helped to identify potential failure mode that happened in the past or similar to the system.

- Severity (S)

  Severity is an assessment of the seriousness of the effect caused. Every failure will be evaluated how badly the effect. There is a direct relationship between effect and severity. For example, if the effect is critical, the severity value will also be high. And if the effects are not critical, the value of severity will be low.

- Occurance (O)

Occurrence is the likelihood that the cause will happen during working. Occurrence is a rating value that adjusts with the estimated frequency of failure that can occur.

- Detection (D)
  Detection is the measurement of the capability of control failure that occurs. The value of detection is associated with the current control.
- Risk Priority Number (RPN)
  RPN is measure that used to assessing the risk to help identify critical failure mode. The range of RPN value is from 1 (good) to 1000 (disaster). The calculation RPN from result FMEA is:

$$RPN = S\ x\ O\ x\ D$$

But for evaluating risk can not only using RPN, because it can cause severe quality problem. It should be considered with a combination of indication ssuch as Severity, Occurance, and Detection to eliminate the risk. The standard used to determine the risk matrix shown in figure below.

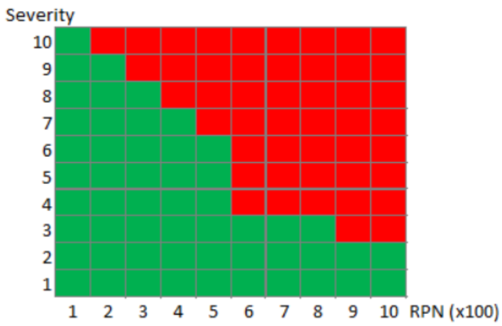

Figure 3. RPN Matrix

Source : IQA System

The advantage of using FMEA for risk assessment is helping for identification failure mode, and action can be taken to reduce failure in the order of quantitatively RPN [6]. However, the disadvantage of FMEA is FMEA is subjective, where the value of RPN based on three-parameter, but these parameters have different concerns.

2.5 Hazard and Operability Study

Hazard and operability study (HAZOP) is one technique to prepare safety in new system or modification to potential hazards. It operates by identifying and evaluating hazards in existing process and operating most effectively and economically. This system using qualitative techniques to identify potential hazard using guide word. The purpose of HAZOP is to identify risk associated with maintenance and manage the system and also to identify potential failure and cause of failure as well as possible equipment irregularity that lead to an accident. The advantage of using HAZOP for risk assessment is that HAZOP can identify the hazard that occurs, the use of keyword is effective, reducing human errors, and HAZOP is arranged systematically. However, the disadvantage of HAZOP, it takes time, not too effective for some failure mode.

2.6 Maintenance Task and Schedule

Maintenance task is series of activities to maintain equipment to keep equipment working according to specified standards. Maintenance task and schedule divided into several categories based on location to carry out the maintenance. Also there are maintendance c interval, which is the period of time maintenance performed on equipment. It needed because the task interval can be done either longer or shorter than existing maintenance schedule with consequences of the maintenance. If the consequence of the failed maintenance activites, the interval should be shorter than existing maintenance schedule to prevent danger of failure equipment during operation time [7]

2.7 Reliability and Failure Rate

2.7.1 Reliability

Reliability is defined to be probability that a component or system will perform a required function for some period of time when used in user needed operating conditions [8]. The reliability is shown as R(t) with the t is time. Generally, reliability measures the ability of the function of equipment within period time without any failure. Reliability has different formulas on each data distribution. These are reliability equation [8] :

$$R(t) = 1 - F(t) = \int_0^\infty f(t)$$

Where:

R(t) : Reliability Function

F(t) : Cumulative Distribution Function (CDF) f(t) : Probability Density Function

2.7.2 Failure Rate

Failure rate is ratio between the number of failures that happen within certain total operating time of component and system. Failure rate has different equations on each data distribution. The failure rate equation are [8]**:**

$$\lambda = \frac{f}{T}$$

Where :

f : number of failures during operation period

T : total operation time

$\lambda(t)$: Failure rate

2.8 Normal and Weibull Distribution

2.8.1 Normal Distribution

Normal distribution, also called gaussian distribution is the most commonly used distribution to explain the spread of data. It also has been sucessfully to model fatigue and wearout phenomena. [8]. The function of normal distribution parameter :

- μ, as mean, is the average of the distribution
- σ, as standard deviation, is the measure of the amount the variation of set a value
- Φ, as

The value of reliability and failure can be identified by using the following equation :

$$R(t) = 1 - \Phi\left(\frac{t-\mu}{\sigma}\right)$$

$$\lambda = \frac{f(t)}{R(t)} = \frac{f(t)}{1 - \Phi\left(\frac{t-\mu}{\sigma}\right)}$$

Where:

t : time

μ : mean

σ : standard devation

2.8.2 Weibull Distribution

Weibull distribution, are almost commonly used in reliability. The model bathub curve is the basis for performing a reliabiliy calculation of a component or system. This distribution can be used for wide data variations. The function of the weibull distribution parameter:

- θ, as a scale parameter, if θ > 0, the distribution will be more spread
- β, as a shape parameter, if β > 1, it indicate the failure rate increase with time
- γ, as a location parameter, if $\gamma = 0$, the distribution will start from t=0

The value of reliability and failure can be identified by using the following equation [8]

$$R(t) = exp\left\{-\left(\frac{t-\gamma}{\theta}\right)^{\beta}\right\}$$

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

Where:

θ : Scale parameter

β : Shape parameter

γ : Location parameter

CHAPTER III
METHODOLOGY

3.1 Working Diagram

The following chart describe the process working of Bachelor Thesis

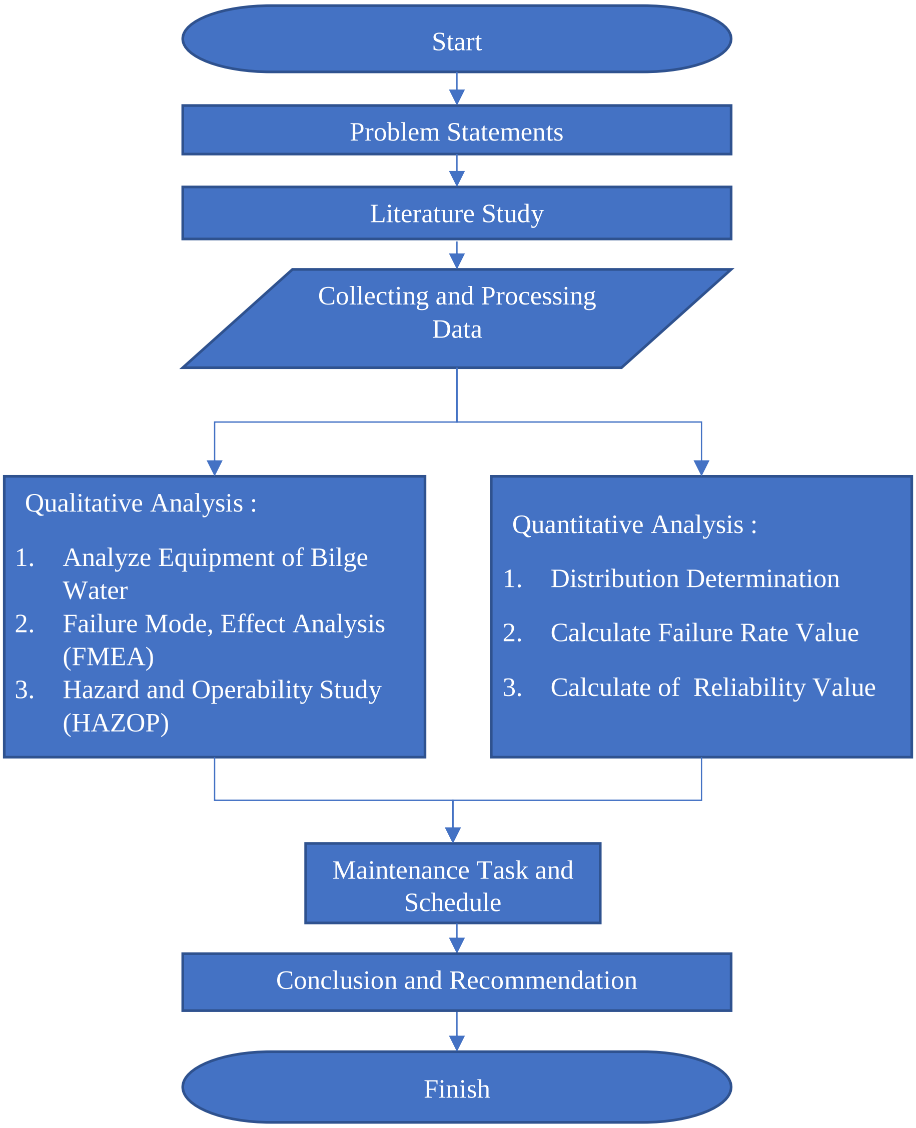

Figure 4 Working Diagram

3.2 Working Process

3.2.1 Literature Study

The literature study that aim to explaining the depth of review, summarizing the basic theory, general and specific reference and obtaining various other supporting information related to the final project. The literature study is done by reading books, guides from ABS, journal and other references.

3.2.2 Data Collection

The data used for this work were obtained from data operational of the system to know about operational history, and data failure & log book that contain information about frequently failure and repair history of each component. Apart from that, look for data in journals too.

3.2.3 Qualitative Method

Qualitative method are used to examine the conditions of equipment with collecting data and analyzing data. The qualitative method used for this thesis is Failure Mode and Effects Analysis (FMEA) and Hazard and Operability Study (HAZOP). Both methods are supported by the American Bureau of Shipping (ABS).

1. Analyze Equipment of Bilge Water System
   Each of equipment on the ship must comply with regulation to ensure the safety of the ship. For bilge system, almost all equipment complies with ABS regulation. And for some equipment, comply with regulation form DNV-GL, MARPOL, and BKI. Every equipment has its own function and interconnected with other equipment to make bilge water system worked. Therefore, P&ID is made more accessible to see the functional relationship between equipment. Piping and Instrument Diagram (P&ID) is a scheme of diagram which shown piping with instrument and control device. P&ID describe all equipment that supports the system operation.
2. Failure Mode and Effects Analysis (FMEA)
   FMEA is a design and engineering tool to analyze potential failure mode within a system to determine the impact of those failure. The technique has been used to minimize failures and reduce safety, environmental and economic impacts that could result from these failures [8]. FMEA usually used to identify potential performance problem in electrical, mechanical, and utility system. The following template of FMEA shown in Table 1.

Table 1. Template of FMEA

System :					
Equipment :					
No	Potential Failure Mode	Potential Failure Effect	Severity (1-10)	Potential Failure Cause	Probability (1-10)

Current Control	Detection (1-10)	RPN	Action Recommended

3. Hazard and Operability Study (HAZOP)
HAZOP analysis technique uses special guide words to suggesting depatures from design intents for section of system and making sure that the control are in place to help prevent system performance problems. HAZOP used for finding safety hazard and operability problems in continous system and also used to review procedure [9]. The following template of HAZOP shown in Table 2.

Table 2. Template of HAZOP

System:				
Equipment:				
No.	Guide Word	Element	Hazard	Possible Cause

Consequences	Control	Action Recommended

3.2.4 Quantitative Method

Quantitative method is a systematic investigation of the event by gathering all measurable data and performing statistical or mathematical techniques. The quantitative method used for this thesis is assisted by ReliaSoft Weibull++ software. ReliaSoft Weibull++ is a comprehensive life data analysis tool that performs life data analysis utilizing multiple lifetime distribution, warranty and degradation data analysis, design of experiment, and more with a clear and intuitive interface geared toward reliability engineering. In this software, all major lifetime distributions, warranty and degradation data analysis, experiment design, and more have a clear and intuitive interface geared toward reliability engineering [10].

1. Determine the distribution

Time to failure (TTF) is time elapsing from when the equipment is put into operation until it fails for the first time. TTF value can be obtained from maintenance data of equipment. Determination of TTF can be used with ReliaSoft Weibull++ software. This software can support all major lifetime distribution and help determine which best distribution with the data already obtained. These are steps to determine the distribution:

- Entering data between failures (hours)

Time Failed
0
15
5.5

Figure 4. Entering TTF Data

- Distribution wizard and ranking methods will automatically performs several types of goodness-of-fit test [9]. Average goodness of fit parameter (AVGOF) shown averages value of difference between result and expected. Average plot fit parameter (AVPLOT) showned averages value of how well ploted points in line straight. And likelihood value (LKV) shown average values of likehood function given the parameter of the distribution.

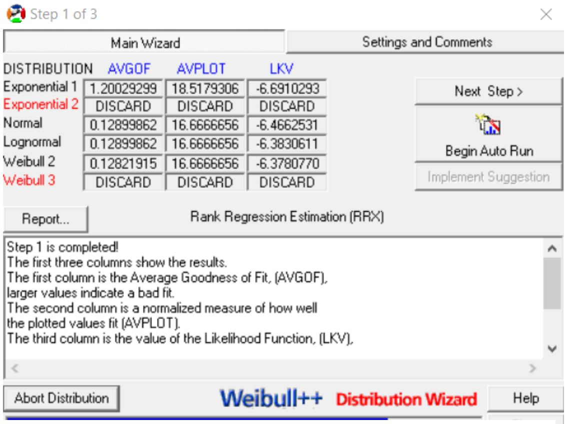

Figure 5. Distribution Testing

- The best result for disribution test can be seen with Begin Auto Run option. It will shows the ranking results of distribution from data being tested.

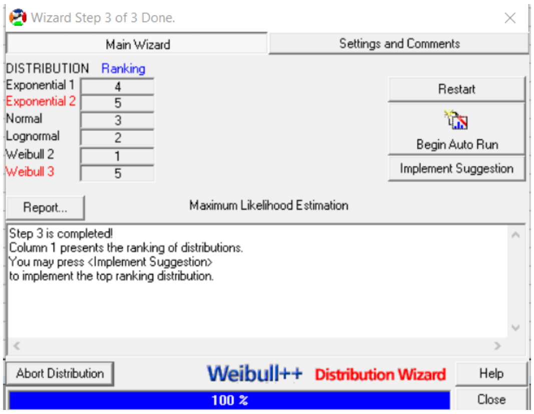

Figure 6. Ranking on Each Distribution

- Implementation suggestion will shown the distribution parameter from data being tested. The distribution may include weibull 2 parameter, weibull 3 parameters, normal distribution, lognormal distribution, and exponential distribution.

Figure 7. Parameter of Distribution

2. Calculate of reliability value
   Based on determination distribution test using ReliaSoft Weibull++ can calculate reliability by using equation from Ebeling. The result of calculation can be plotted into graphic to shown relationship between reliability equipment and operational time.
3. Calculate of failure rate value
   Based on determination distribution test using ReliaSoft Weibull++ can calculate failure rate by using equation from Ebeling. The result of calculation can be plotted into graphic to shown relationship between failure rate equipment and operational time.

3.2.5 Maintenance Task and Schedule

After selecting the suitable risk assessment for bilge water system, it is necessary to set schedule maintenance and know the proper maintenance task. It must be applied to every equipment to avoid failure. If failure occurs during operation time, the system will not be working and stop. This research determines the maintenance task and schedule based on selection risk assessment (FMEA & HAZOP). The following template of maintenance task and schedule shown in Table 3.

Table 3. Template of Maintenance Task

SUMMARY OF MAINTENANCE TASKS				
System:				
Equipment:				
Task	Task Type	Item No.	Risk	
			Unmitigated	Mitigated

Frequency	Procedure No or Class Reference	Comments

3.2.6 Conlusion

The final step is to make conclusion of the entire process. Based on the result of the analysis, it is determined the recommendation for maintenance action taken against failure occur.

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CHAPTER IV
MODELING AND ANALYSIS

4.1 Qualitative Method

4.1.1 Analyze Component of Bilge System

The first stage of qualitative stage is to analyze the component of bilge water system. The function of equipment, the size of the equipment, and the placement comply with the regulation. The list of component bilge water system is presented in **Appendix 1.** And P&ID is more accessible to see the functional relationship between equipment. P&ID in this thesis is presented in **Appendix 2.**

4.1.2 Failure Mode and Effects Analysis (FMEA)

After known the equipment and their function for bilge water system, then next performed FMEA using standard ABS Guidance Notes. Before starting FMEA, select the equipment to be analyzed. And then identify the failure mode that may occur on the equipment. After that, determine the cause of the failure mode and degree of impact the failure mode. Determine the critical level of failure mode can use risk assessment standards. Repeat the step until all components and all failure mode has been evaluated. If the analysis is complete, the result of FMEA can be present in **Appendix 3.**

4.1.3 Hazard and Operability Study (HAZOP)

Besides using FMEA, HAZOP is one of the risk assessment that considered for maintenance strategies. HAZOP is suitable for assessing hazard in equipment with capable assessing from multiple perspectives. First, select the equipment to be analyzed. Second, combining the guide words and parameter of equipment. Role of guide word is to focus the study and stimulate brainstorming. And then identify the cause of hazard and evaluating consequences. Repeat the step until all components and all failure mode has been evaluated. If the analysis is complete, the result of HAZOP can be present in **Appendix 4.**

After analyzing failure mode in bilge water system with two risk assessments, HAZOP was chosen as the right risk assessment to apply in this thesis. FMEA was not selected because the value of the RPN does not guarantee an acceptable. After all, three individual parameters must be considered for how severe the risk is.

4.2 Quantitative Method

4.2.1 Quantitative Analysis Pump

Based on the data [11], the following Table 4 is result of processing TTF (Time to Failure) for Pump cause by the impeller.

Table 4. Time to Failure Pump

No.	Time to Failure (hr)	Failure Mode
1.	1276	Impeller
2.	1942	Impeller
3.	583	Impeller
4.	172	Impeller
5.	1456	Impeller

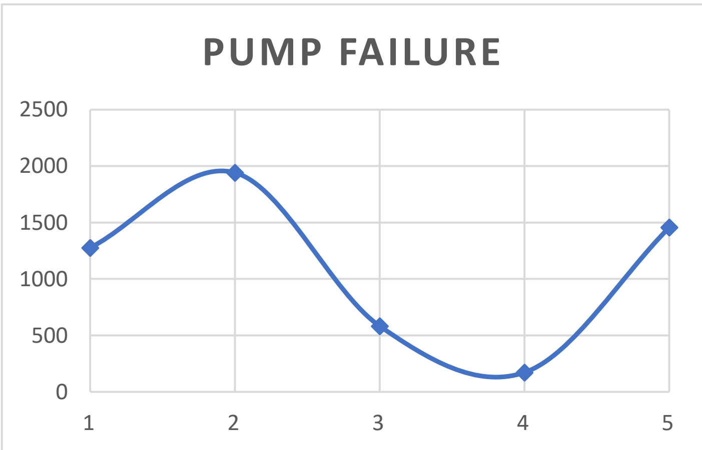

Figure 8. Time to Failure Graph of Pump

Based on the graph above, it can be seen how severe the effects of impeller failure are. The failure caused by the impeller is incorrect impeller adjustment, wear out, and uniform corrosion on the surface. The failing impeller causing a downtime and un-planned maintenance cost high. Because of that, the maintenance strategies are replaced from time-based maintenance to run-to-failure maintenance, and have to planned maintenance costs and un-planned maintenance costs [10].

Furthermore, from result of ReliaSoft Weibull++ data distribution for pump is normal distribution. The value of mean (μ) is 1085.8 and standard deviation (σ) is 802.005. The following table x is reliability data using time interval 500 hours**.** The reliability formula is included in the column adjusted for the distribution and same way for the failure rate.

Table 5. Reliability and Failure Rate Data of Pump

RELIABILITY				
NORMAL DISTRIBUTION			FROM TTF	
t (hours)	R(t)	λ(t)	mean (μ)	std (σ)
0	0.91211	0.000218	1085.8	802.005
500	0.767434	0.000496	1085.8	802.005
1000	0.548599	0.000912	1085.8	802.005
1500	0.302767	0.001438	1085.8	802.005
2000	0.127164	0.002043	1085.8	802.005
2500	0.038921	0.002700	1085.8	802.005
3000	0.008498	0.003391	1085.8	802.005
3500	0.001305	0.004105	1085.8	802.005
4000	0.00014	0.004835	1085.8	802.005

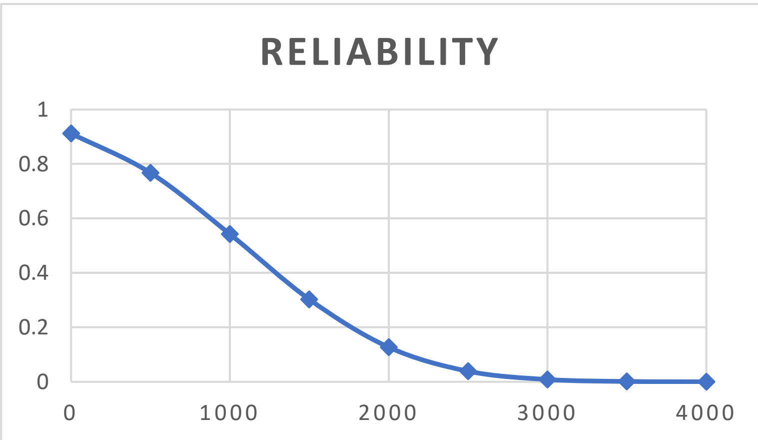

Figure 9. Reliability Graph of Pump

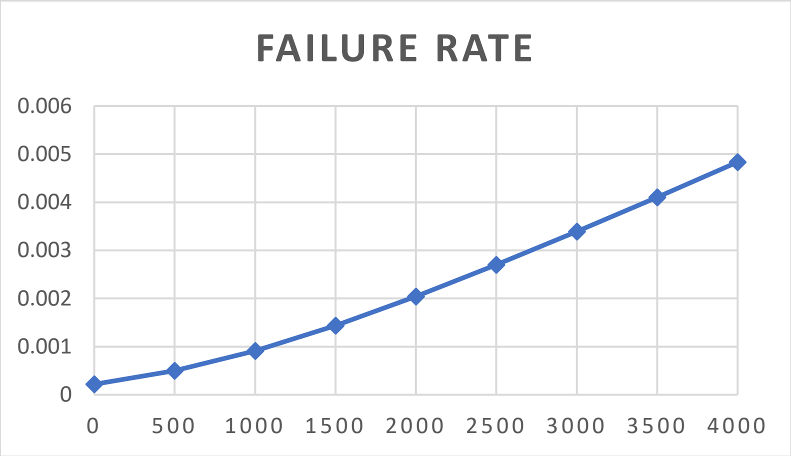

Figure 10. Failure Rate of Pump

Based on Figure 9 and Figure 10, it can be seen that the reliability of the equipment decreased and the failure rate of the equipment increased as time went. So the maintenance action can be performed on pump.

4.2.2 Quantitative Analysis Pipe, Strainer and Valve

Due to the limited data obtained, for quantitative analysis pipes, strainers and valves are calculated same as a quantitative analysis pump.

4.2.3 Quantitative Analysis Tank

Based on the data [12], the year build of the ship is December 2017. And with there are an annual survey, it can be considered there sometimes the tank will not be used.

Table 6. Maintenance Data of Tank

START	FINISH	HOURS
	8/12/2017	0
8/12/2017	8/12/2018	8760
8/12/2018	8/12/2019	8760
8/12/2019	1/03/2020	2016

Using the same method in section 3.2, the result from software is Weibull 2 parameter distribution. The value of beta (β) is 1.2569 and eta (η) is 7730.87. The following table x is reliability data using time interval 2000 hours. The reliability formula is included in the column with adjusted for the distribution and same way for the failure rate.

Table 7. Reliability and Failure Rate of Tank

RELIABILITY				
WEIBULL DISTRIBUTION			**FROM TTF**	
t(hours)	R(t)	λ(t)	beta (β)	eta (η)
0	1	0	1.2569	7730.87
2000	0.832944	0.000115	1.2569	7730.87
4000	0.64608	0.000137	1.2569	7730.87
6000	0.483268	0.000152	1.2569	7730.87
8000	0.352061	0.000164	1.2569	7730.87
10000	0.251094	0.000174	1.2569	7730.87
12000	0.175901	0.000182	1.2569	7730.87
14000	0.121314	0.000189	1.2569	7730.87
16000	0.082509	0.000196	1.2569	7730.87
18000	0.055414	0.000202	1.2569	7730.87

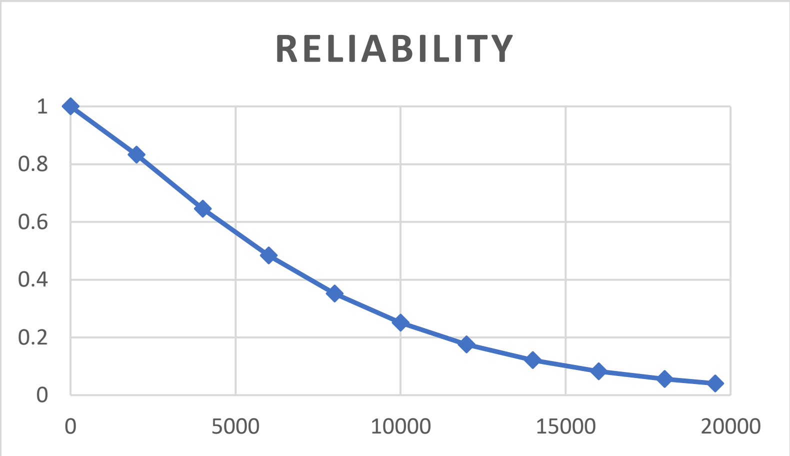

Figure 11. Reliability Graph of Tank

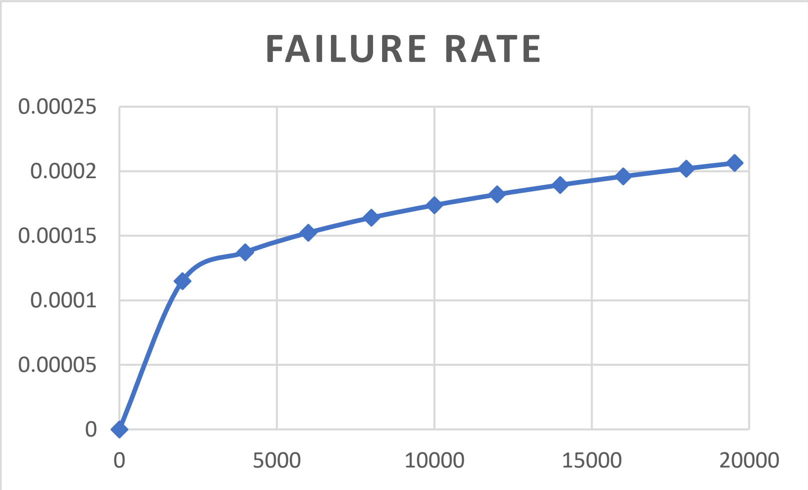

Figure 12. Failure Rate of Tank

Based on Figure 11 and Figure 12**,** it can be seen that the reliability of the equipment decreased and the failure rate of the equipment increased as time went. So the maintenance action can be performed on tank.

4.2.4 Quantitative Analysis Oil Filtering Equipment and Sensor

Based on the data [13], there are failured with oil filtering equipment and sensors during the working period.

Table 8. Maintenance Data of Oil Filtering Equipment and Sensor

START	FINISH	HOURS
	8/12/2017	0
8/12/2017	27/10/2019	15
16/12/2019	03/04/2020	5.5

Using the same method in section 3.2, the result from software is Weibull 2 parameter distribution. The value of beta (β) is 2.3914 and eta (η) is 11.6411. The following table x is reliability data using time interval 5 hours. The reliability formula is included in the column with adjusted for the distribution and same way for the failure rate.

Table 9. Reliability and Failure Rate Data of Oil Filtering Equipment and Sensor

RELIABILITY				
WEIBULL DISTRIBUTION			**FROM TTF**	
t (hours)	R(t)	λ(t)	beta (β)	eta (η)
0	1	0	2.3914	11.6411
5	0.875881	0.063384	2.3914	11.6411
10	0.498917	0.166278	2.3914	11.6411
15	0.159849	0.292313	2.3914	11.6411
20	0.026041	0.436202	2.3914	11.6411
25	0.001989	0.595015	2.3914	11.6411

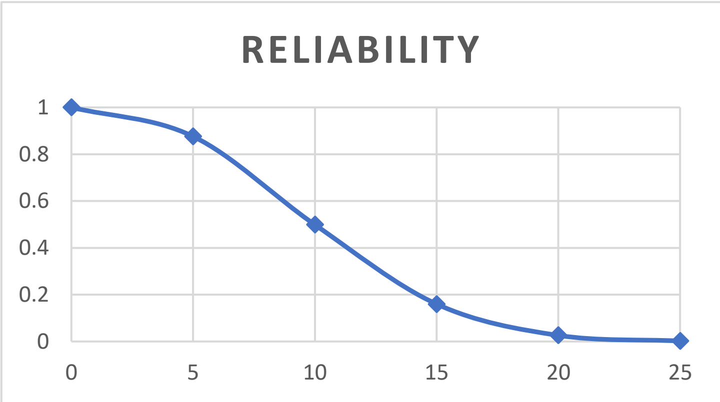

Figure 14. Reliability Graph of Oil Filtering Equipment and Sensor

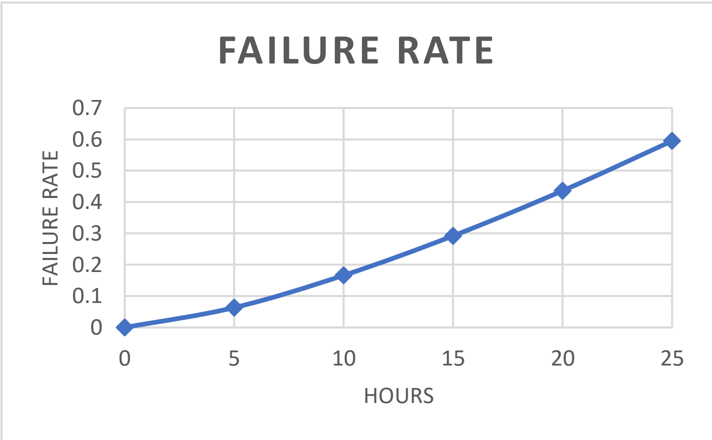

Figure 13. Failure Rate Graph of Oil FIltering Equipment and Sensor

Based on Figure 13 and Figure 14**,** it can be seen that the reliability of the equipment decreased and the failure rate of the equipment increased as time went. So the maintenance action can be performed on oil filtering equipment and sensor

4.3 Maintenance Task and Schedule

Based on the result from every failure mode that has been done identification, then will do task selection. Task selection is to determine action or decision to applied maintenance with the right type of maintenance. Each recommended maintenance action will divided into several categories, Preventive Maintenance (PM), Condition Monitoring (CM), and Failure Finding (FF). The result of summary maintenance task shown in **Appendix 5.**

CHAPTER V
CONCLUSION

5.1 Conclusion

Based on qualitative analysis from the discussion and research, it can be concluded that all equipment can occur failure in the bilge water system. With analysis from two risk assessments, each risk assessment has a different advantage and disadvantage. Therefore, both of them can be used with circumstances if you want to assess the failure mode. Every equipment has a failure mode in various ways. There are incomplete working equipment, worn out, equipment broken, etc. And based on quantitative, every equipment will experience decreased reliability and increased failure rate as time went by. However, it can all be avoided by doing maintenance action. Every maintenance task is done to determine the appropriate type of maintenance. Each of tasklist selected based in guide books from the equipment. However, the tasklist must be confirmed with the crew of the ship, and the shipping company by considering how severe the risk is. Therefore, with maintenance, failure can be avoided.

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APPENDIX 1

No	Equipment	Function	Reference	Requirement
1.	Bilge Well	Storage that holds fluid that will be discharged		Bilge well installed in each compartment below the waterline and not covered by the other system
			DNVGL 4-6-4/8.6.1	The bilge wells shall have capacity of at least **0.15m^3**
2.	Bilge Main Suction	To suction the fluid	ABS Rules 4-6-4/5.3.1 (a)	The diameter of the main bilge line suction is to be determined by the following equations : $d = 25 + 1.68\sqrt{L(B+D)}mm$ $d = 1 + \sqrt{\frac{L(B+D)}{2500}}in$ However, **no bilge main suction pipe is to be less than 63 mm (2.5 in) internal diameter.**
3.	Bilge Branch	To connect the main bilge pipe to the compartment from where water is to be pumped out	ABS Rules 4-6-4/5.3.1 (d)	The diameter of the bilge branch suction for a compartment is to be determined by the following equation. If the compartment is served by more than one branch suction, the combined area of all branch suction pipes is not less than the area corresponding to the diameter determined by the following equation

				$d_s = 25 + 2.16\sqrt{c(B+D)}mm$ $d_s = 1 + \sqrt{\frac{c(B+D)}{1500}}in$ However, **no branch suction pipe needs to be more than 100 mm (4 in) internal diameter**, nor is to be less than 50 mm (2 in) internal diameter, expect that for pumping out small pockets or spaces, 38 mm (1.5 in) internal diameter pipe may be used
4.	Bilge Pipe	Pipe to transfer the bilge water	MSIS 27/CH 5/5.4.1	Bilge pipes in machinery spaces should be of material having a melting point of not less than 800 C. New pipes should be of galvanized steel or similar corrosion-resistant material.
			ABS Rules 4-6-4/5.5.12	Bilge pipes installed within the regions of assumed damage under damage stability conditions are to be considered damaged.
5.	Strainer	Filter out foreign materials entering the pump	ABS Rules 4-6-4/5.5.3 (a)	Bilge lines in machinery spaces other than emergency suctions are to be fitted with strainers, easily accessible from the floor plates and are to have straight tail pipes to the bilges.

6.	Valve	A tool to control the flow of the fluid by opening and closing	ABS Rules 4-6-4/5.5.4 (a)	Bilge valves are located in positions which are accessible at all times for maintenance under ordinary operating conditions. All type of valves must be stop-check valve.
			ABS Rules 4-6-4/5.5.4 (b)	Where a bilge pump is connected for bilge, ballast, and other sea water services, the bilge suction main, the ballast suction main, etc. are each to be provided with a stop valve, so that when the pump is used for one service, the other services can be isolated.
7.	Bilge Pump	A pump used to suction water from the bilge to be discharged	ABS Rules 4-6-4/5.5.2 (a)	The number of pumps: At least **two power-driven** bilge pumps are to be, one of which may be driven by the propulsion unit.
			ABS Rules 4-6-4/5.5.2 (b)	Permissible use of other pumps: Sanitary, ballast, and general service pumps may be accepted as independent power bilge pumps, provided they are required capacity, not normally used for pumping oil, and are appropriately connected to the bilge system
			ABS Rules 4-6-4/5.3.2	**Each pump capable of giving a speed of water through bilge main not less than 2**

				m/s. The minimum capacity Q of the required bilge pump may be determined from the following equation: $$Q = \frac{5.66d^2}{10^3} m^3/hr$$ $$Q = 16.1d^2 gpm$$ When more than two pumps are connected to the bilge system, their arrangement and aggregate capacity are not to be less effective.
8.	Level Sensor	Sensor to determine the level of fluid	ABS Rules 4-6-4/5.5.5 (c)	When the propulsion machinery space is intended for centralized or unattended operation, a high bilge water level alarm system is to be fitted.
9.	Pressure Sensor	Sensor to determine the pressure of gasses or liquid		
10.	Oil Filtering Equipment	Equipment that is filtering the content of oil in the water before discharge through overboard	MARPOL Annex I, Chapter 3, Part B, reg.14.1	Any ship of 400 gross tonnages and above but less than 10.000 gross tonnages shall be fitted with oil filtering equipment complying with paragraph 6 of this regulation.
			MARPOL Annex I, Chapter 3, Part B, reg.14.6	Oil filtering equipment referred to in paragraph 1 of this regulation shall be design approved by the Administration and shall be such as will ensure that any oily

				mixture discharged into the sea after passing through the system has an oil content not exceeding **15 parts per million**.
11.	Oil Content Monitor	Device to measuring of the oil content in the water		
12.	Sludge Tank	A tank that receive oily residues from oily water filtering.	ABS Rules 4-6-4/5.7.3	The sludge tank is to be designed to facilitate cleaning. Where heavy fuel oil residue is expected to be received by the sludge tank, heating arrangements are to be provided to facilitate the discharge of the sludge tank. The minimum sludge tank capacity V1 is to be calculated by the following formula: $V_1 = K_1 C D m^3 (ft^3)$
13.	Bilge Holding Tank	A tank collecting oily bilge water to be discharged	BKI Rules for Machinery Installations 2016 Section 11.3.3.1	An oily bilge holding tank shall be provided. This tank should preferably be a deep tank arranged above the tank top, which safeguards the separations of oil and water. Appropriate draining arrangements for the separated oil shall be provided at the oily bilge water holding tank.
			BKI Rules for Machinery	Oil residues (sludge) and oily bilge water tanks shall be

			Installations 2016 Section 11.3.3.2	independent of each other.
			IMO 2008/8.3	Oily bilge holding tanks should have capacity that provides to the ship the flexibility of operation in ports, coastal waters and special area, without the need to discharge de-oiled water overboard. The recommended capacity of oily bilge water holding tanks are: Up to 1.000 kW : 4 m^3 Above 1.000 up to 20.000 : Main Engine kW (P)/250 Above 20.000 : 40+P/500
14.	Sludge Pump	A pump used to distribute waste of oil to discharge connection	ABS Rules 4-6-4/5.7.4 (a)	The sludge tank is to be provided with a designated pump of a suitable type, capacity and discharge head for the discharge of the tank content to shore reception facilities
15.	Standard Discharge Connection	To remove sludge shore	MARPOL Annex I, Chapter 3, Part A, Reg.13	To enable pipes of receptions facilities to be connected with the ship's discharge pipeline for residues from machinery bilges and from sludge tanks, both line shall be fitted with a standard discharge connection in accordance with the following requirements: - Outside diameter: 215 mm

				- Inner diameter: according to pipe outside diameter - Bolt circle diameter: 183 mm - Slots in flange: 6 holes 22 m in diameter equidistantly placed on a bolt circle of the above diameter, slotted to the flange periphery. The slot width to be 22 mm. - Flange thickness: 20 mm
16.	Emergency Bilge Suction	Direct suction from machinery space to the largest capacity pump to prevent flooding of the ship	ABS Rules 4-6-4/5.5.5 (b)	An emergency bilge suction is to be fitted for the propulsion machinery space. The emergency bilge suction is to be directly connected to the largest independently driven pump in the propulsion machinery space, other than the required bilge pumps. Where this pump is not suitable, the second-largest suitable pump in the propulsion machinery space may be used for this service, provided that the selected pump is not one of the required bilge pumps and its capacity is not less than that of the required bilge pump.

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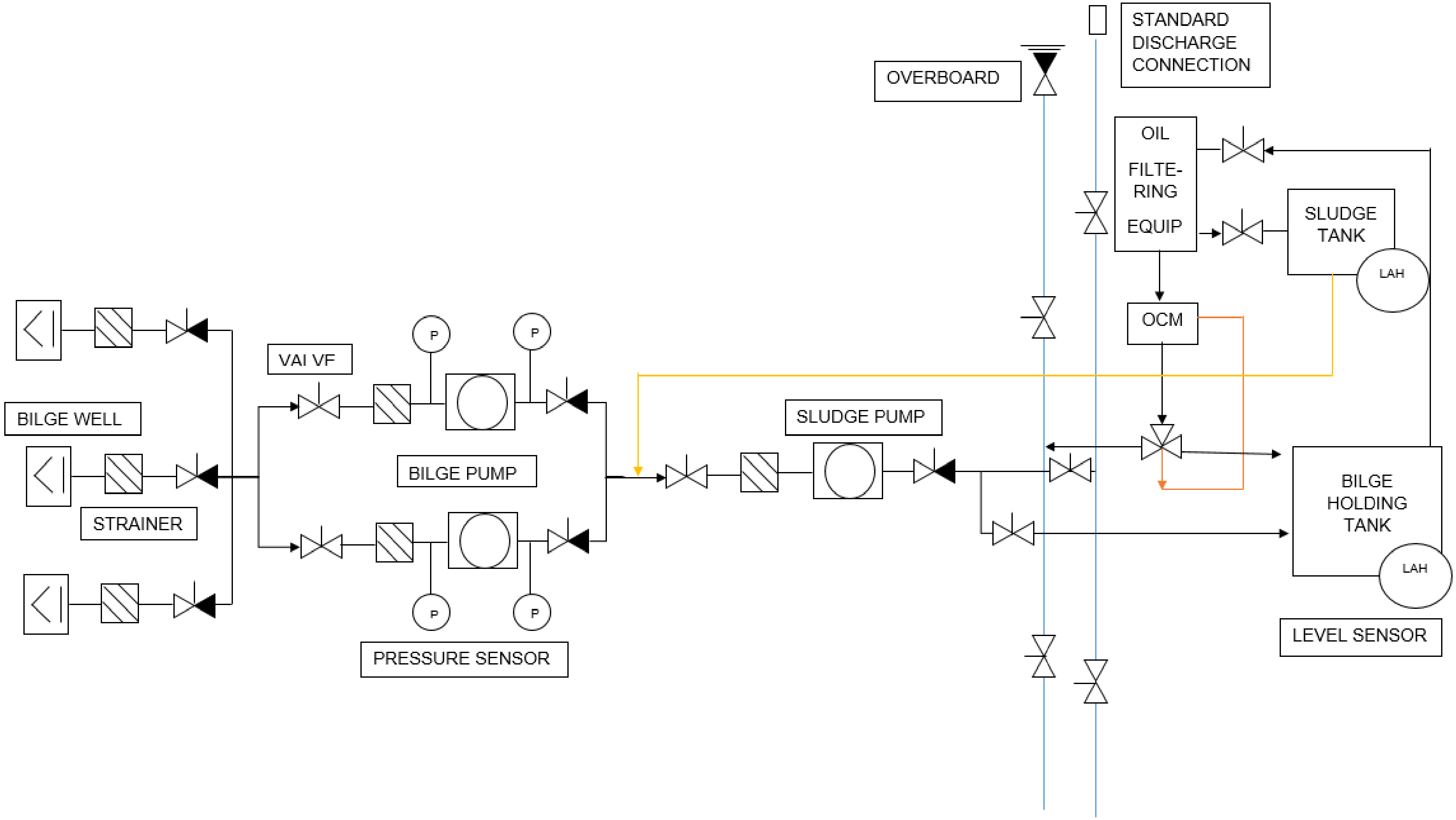
APPENDIX 2



STANDARD DISCHARGE CONNECTION
OVERBOARD
OIL FILTE-RING EQUIP
SLUDGE TANK
LAH
OCM
BILGE WELL
VAI VF
P
P
SLUDGE PUMP
BILGE PUMP
BILGE HOLDING TANK
STRAINER
LAH
P
P
PRESSURE SENSOR
LEVEL SENSOR

APPENDIX 3

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Pump									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Failed to deliver water	No bilge water deliver	8	Head suction too high, pump is broken	2	Stop the pump	6	96	Standby pump will resume the work
2.	Pump is not priming	Pump will lead to fracture	5	Air leakage into the flow	4	Stop the pump	4	80	Examined priming gear
3.	Not enough deliver water	Decreased pressure flow of water	7	Pump cavitation	6	Stop the pump. Standby pump will resume the work	5	210	Examined the pump. Install an impeller inducer. Try to reduce the temperature the pump
4.	Takes too much power	Pump overload	9	Electric defects	6	Stop the pump. Standby pump will resume the work	4	144	Check the voltage and frequency of the pump.
5.	Operates for short time and stop	Incomplete deliver waters as expected	5	Incomplete priming	4	Stop the pump. Standby pump will resume the work	5	100	Free valve, pipe, and pump from all air

6.	Preassure bottle up	Explosion	10	Relief valve closed	5	Pressure sensing Monitor temperature	4	200	Check relief valve and do maintenance regularly
7.	Failed build up the pressure	Slow down the flow	6	Worn out	4	Check if there any leak in pipe and pump	5	120	Examined the pump
8.	Noise and vibration	Pump will lead to fracture	5	Worn out	4	Check alignment of pump	4	80	Examine the pump (bearings, impeller)

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Pipe									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Corrosion	Lead to fracture	6	pH content in water, oxygen content, velocity of flow	2	Check for any slow down performance	6	72	Clean regularly and coating pipe
2.	Cracking	Leakage	5	Repeated stresses	2	Check for any leakage	6	60	Examine the pipe

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Strainer									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Clogging	Slow down the flow of water	5	Blockage from solid contamination	6	Avoid sudden process change	6	180	Check and clean the strainer
2.	Internal leak	Micro particel passing through	3	Worn out	4	Check quality of filter	3	36	Check and change the strainer

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Valve									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Corrosion	Lead to fracture	7	pH content in water	7	Try to wash and flush inside and outside the body valve	3	147	Change the flow of pipeline, change the valve, and coating the valve
2.	Fail to flow the water	Cannot be operate	8	Trouble filter	4	Try to wash and flush inside the	4	96	Change the flow of pipeline, replace the filter

						body valve. Discharge the drain			
3.	Seal leak	Leakage when fully closed	3	Wear out	4	Polish the valve	2	24	Change the flow of pipeline, change the valve

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Sensor									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Overfilling	Overflow fluid	8	Level indicator fail read value	4	Check with visual test (cross check with level value)	6	72	Do maintenance regularly
2.	Out of signal	Send false signal	7	Hardware failure	4	Check with visual test	5	140	Stop the sensor

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Tank									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Cracking	Leakage to machinery space	5	Mechanical stress	2	Check condition of the tank (visual)	6	60	Examine the tank (leakage test)
2.	Clogging	Slow down the flow	5	Blockage from solid sediment	6	Check condition of the tank (visual)	5	150	Examine and clean the tank

FMEA									
System : Bilge and Oily Bilge System									
Equipment : Oil Filtering Equipment									
No.	Failure Mode	Potential Effect	S (1-10)	Potential Cause	O (1-10)	Curent Control	D (1-10)	RPN	Action Recommended
1.	Fail to deliver	No oily water deliver	8	Pump is not working	5	Automatically stop processing	4	160	Examine the pump
2.	Fail to do visual and testing test	Cannot do the test for reporting	9	Test cock valve is broken	4	Clean the surface area of test cock	3	108	Check and replace the test cock
3.	Fail to build up pressure	Pressure leakage	6	Air vent valve shut down automaticaly	5	Automatically stop processing	4	120	Check and replace the valve

4.	Fail read value of oil	Value of oil in the water (> 15 ppm) pass through	9	Oil content Monitor (OCM) is broken	4	Automatically stop processing	4	144	Examine the OCM. If too damage, replace it
5.	Noise and vibration	Lead to fracture	5	Worn out	4	Check condition of pump and motor	4	80	Examine the pump and motor (bearings, and etc.)

APPENDIX 4

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Pump							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Suction	No bilge water is sucked into pump	Head suction too high	No flow of bilge water	Stop the pump	Standby pump will resume the work
2.	No	Priming pump	Pump is not priming	Air leakage into the flow	Pump will lead to fracture	Check for any leak in pump or pipe	Examined priming gear
3.	Less	Flow	Less flow of bilge water than expected	Pump cavitation	Decreased flow of water	Stop the pump. Standby pump will resume the work	Examined the pump
4.	More	Electricity	Takes too much power	Electric defect	Pump overload	Stop the pump. Standby pump will resume the work	Check the voltage and frequency of the pump
5.	Less	Time	Only working for short time	Incomplete priming	Incomplete deliver water	Stop the pump. Standby pump will resume the work	Free valve, pipe and pump from all air

6.	More	Pressure	Pressure bottle uo	Relief valve closed	Explosion	Pressure sensing Monitor temperature	Check relief valve and do maintenance regularly
7.	Less	Pressure	Pump is failed build pressure completely	Worn out	Slow down the flow of bilge water	Stop the pump. Check a all valves in suction line are open	Examined the pump
8.	Part of	Bolt off	Detect noise and vibration when pump started	Worn out	Pump will lead to fracture	Check alignment of pump	Examine the pump (bolts, bearings, impeller)

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Pipe							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Flow	No flow of water in pipeline	Pipeline being blocked Malfunction of valve	No flow of bilge water	Check if there any clogging on pipe	Examine and maintaining the pipe
2.	Low	Flow	Low flow of water than expected	Pipeline has some leakage	Low flow of water	Check if there any leakage	Examine the pipe and pipe material

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Strainer							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Cleaning	Clogging on strainer	Blockage from solid sediment	No or low flow of bilge water	Avoid sudden change process to prevent more clogging	Check and clean the strainer
2.	More	Particle	Internal leakage	Worn out	More particle passing through	Check the quality of strainer	Check and change the strainer

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Valve							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Flow	No water that flow from valve	Valve failed to open Valve blocked	No flow of bilge water	Check if valve being blocked or malfunction	Maintaining valve regularly
2.	More	Flow	Overflow	Valve failed to closed Seal leakage when closed	Overload and leakage	Check connection line the valve Check if there any leakage	Change the flow of pipeline, check the seal of valve, change the valve
3.	More	Flow	Seal leak	Worn out	Leakage	Polish the valve	Change the flow of pipeline, change the valve

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Sensor							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	Low	Level	Nor or less water in tank	Valve failed to open Cracking or corrosion of the tank	Change in volume of water	Check with visual test	Install Low Alarm Level (LAL) Maintenance regularly
2.	High	Level	More water in storage tank	Valve failed to closed Level indicator failed	Overfilling the tank	Check with visual test	Maintenance regularly

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Tank							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Flow	No flow of water to the tank	Pump failed Outlet valve blocked Pipeline rupture	Pressure increase in pipeline Consequently leak	Check with visual test	Examine the pump and the valve Clean the valve

2.	Less	Flow	Less flow of water to the tank as expected	Minor leak from pipeline	Leak of bilge water into the ship Possibility of build up pressure in pipeline	Check with visual test	Examine the pipeline

HAZOP							
System : Bilge and Oily Bilge System							
Equipment : Oil Filtering Equipment							
No.	Guide Word	Element	Hazard	Possible Cause	Consequences	Control	Action Recommended
1.	No	Flow	No flow of oily water	Pump is not working	Fail to deliver oily water	Automatically stop the process	Examine the pump
2.	No	Testing	Fail testing visual of oil	Test cock valve is not working	Cannot do testing for reporting	Clean the area surface of valve	Check and replace the valve
3.	Wrong	Signal	Wrong sending signal of value content the oil	Oil Content Monitor (OCM) is not working	Value of oil (>15 ppm) discharged to the ocean	Automatically stop the process	Examine the OCM. Replace if it too damage
4.	Less	Pressure	Fail to build up pressure	Air vent valve shut down	Pressure leakage	Automatically stop the process	Check and replace the valve
5.	Part	Bolt off	Detect noise and vibration when pump started	Worn out	Lead to fracture	Check condition of pump and motor	Examine the pump and motor (bearings, and etc.)

APPENDIX 5

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Pump					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Functional test	FF	1.1	Occasional	Low	Once per voyage	-	-
Check self-priming pump	CM	1.2	Probable	Medium	Every 18 months	-	-
Overhaul pump motor	PM	1.3	Occasional	Low	Every 18 months	-	-
Electric motor overhaul	PM	1.4	Occasional	Low	Every 18 months	-	-
Overhaul pump motor	PM	1.5	Occasional	Low	Every 18 months	-	-
Functional test	FF	1.6	Low	Medium	Every 3 months	-	-
Starter inspection	FF	1.7	Probable	Medium	Every 6 months	-	-
Check allignment of pump	CM	1.8	Probable	Medium	Every 3 months	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Pipe					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Inspection	FF	2.1	Probable	Medium	Every 6 months	-	-
Checking for any leakage	PM	2.2	Probable	Medium	Every 1 month	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Strainer					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Checking and record any difference and self-cleaning	CM	3.1	Probable	Medium	Daily	-	-
Checking for any leakage	PM	3.2	Probable	Medium	Every 1 month	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Valve					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Drain out fluid, valve check	CM	4.1	Probable	Medium	Every 3 months	-	-
Disassemble and cleaning valve	CM	4.2	Probable	Low	Every 6 months	-	-
Check for any leakage	PM	4.3	Occasional	Low	Every 3 months	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Sensor					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Functional test	FF	5.1	Low	Medium	Every 1 month	-	-
Electrical functional test	PM	5.2	Probable	Medium	Every 1 month	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Tank					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Checking for any leakage	PM	6.1	Probable	Medium	Every 12 month	-	-
Cleaning	PM	6.2	Probable	Medium	Every 12 month	-	-

SUMMARY OF MAINTENANCE TASKS							
System:		Bilge and Oily Bilge System					
Equipment:		Oil Filtering Equipment					
Task	Task Type	Item No.	Risk		Frequency	Procedure No or Class Reference	Comments
			Unmitigated	Mitigated			
Functional test	FF	7.1	Probable	Medium	Once per voyage	-	-
Visual inspection of oil content	CM	7.2	Medium	Medium	Once per voyage	-	-
Starter inspection	FF	7.3	Probable	Medium	Every 6 months	-	-
Check alarm system	CM	7.4	Low	High	Once per voyage	-	-
Check noise and vibration	CM	7.5	Probable	Medium	Every 3 months	-	-

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