CHALMERS

Combustion engine failures

An analysis of accidents, incidents and near misses surrounding marine combustion engines onboard ships

Bachelor thesis in Marine engineers

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Gothenburg, Sweden 2018

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Abstract

The maritime industry transports the majority of all cargo worldwide. The work onboard requires a crew that has competence to safely take the ship from A to B. In the maritime area, hazardous situations where loss of electricity or loss of propulsion can affect the environment and the people involved. Marine combustion engines have complex systems that need to be reliable for both generating electricity and to safely propel the ship for safe trading. The engine room environment is a strenuous area, it´s noisy, humid and vibrating which can affect both how the crew performs jobs and the machinery and its components lifetime.

The study is a secondary quantitative analysis which investigates the causes of marine combustion engine failure in the span of 2007-2017 by using reports from the voluntary Insjörapport, submitted to the incident database ForeSea. The database receives accident, incident and near-miss reports from a number of shipping companies mainly located in Scandinavia.

The result divides failures into 5 main categories: component, operator, fuel, automation system and uncertain. The most common cause was found a mechanical or electrical component and maintenance by operator. The rest of the reports represent 35% of all failures.

Keywords: Blackout, engine failure, loss of propulsion, maritime, Near-miss, Incident, Accident.

Sammanfattning

Sjöfartssektorn transporterar majoriteten av all last över hela världen. Arbetet ombord kräver en besättning som har kompetens att säkert ta skeppet från A till B. I sjöfartsområdet kan farliga situationer med förlust av el eller förlust av framdrivning påverka miljön och de inblandade personerna. Marina förbränningsmotorer har komplexa system som måste vara tillförlitliga för både elproduktion och för att säkert driva fartyget under säker handel. Motorrummiljö är ett ansträngt område som är bullrigt, fuktigt och vibrerande, vilket kan påverka både hur besättningen utför jobb och maskineri och dess komponenters livslängd.

Studien är en sekundär kvantitativ analys som undersöker orsakerna till marina förbränningsmotorers misslyckanden under perioden 2007-2017 genom att använda rapporter från frivilliga Insjörapporter som skickades till incidentdatabasen ForeSea. Databasen tar emot olyckshändelser, incidenter och närmaste rapporter från ett antal rederier som huvudsakligen är belägna i Skandinavien.

Resultatet delar upp misslyckanden i fem huvudkategorier: komponent, operatör, bränsle, automationssystem och osäker. Den vanligaste orsaken visade sig vara en mekanisk eller elektrisk komponent och underhåll av operatören. Resten av rapporterna utgör 35% av alla misslyckanden.

Nyckelord: Blackout, motorfel, förlorad framdrift, sjöfart, nära miss, incident, olycka.

Preface

The authors would like to thank:

Dr. Monica Lundh at Chalmers University of Technology, our supervisor, for all of the guidance that has helped us to construct this bachelor thesis.

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Abbreviations and concepts

DNV = Det Norske Veritas.

DNV-GL = a merger of the classification societies DNV and Germanischer Lloyd.

DP = company Designated Person.

ECA = Emission Control Area.

EMSA = European Maritime Safety Agency.

Gen sets = Generator sets. A generator connected to an alternator.

HFO = Heavy fuel oil.

HT = High temperature.

IACS=International Association of Classification Societies

IRIS = Improvement Reporting Information System.

ISM = International safety management.

ISO = International Organization for Standardization.

LT = Low temperature.

MPMS= Machinery planned maintenance system.

MT=Motor tanker.

RMS=Royal Mail Ship.

PMS = Power Management System.

SOLAS = Safety Of Life At Sea.

SW = Seawater.

1 Introduction

The maritime industry is a fundamental part of the global transport, with shipping representing more than 90 % of the transports in volume 2007. The industry is the most economical and safe way to carry and connect all the continents (Lun, Cheng & Lai 2010 Ch.1). In 2017 there were more than 50 000 ships registered in the world for trading. (Marine Flottenkommando, 2018). The sea is a multicultural workplace and the crew are responsible for the working environment onboard. Even though serious accidents occur onboard with consequences that can lead to material damage on ships, human lives or marine environmental pollution, after almost every accident internal rules are created or changed to prevent injuries and casualties (Ćorović & Djurovic, .2013). When major accidents like the loss of RMS Titanic occur regulations like Safety Of Life At Sea (SOLAS) are instituted (Li & Wonham, 2010).

European Maritime Safety Agency's (EMSA) *"annual overview of marine casualties and incident 2017"* presents statistical analyses, from the years 2011-2016, of marine casualties and incidents regarding vessels that belong to European Union states, operating in EU waters or if the vessel is of EU interest. A total of 18 655 ships were involved in the investigation by EMSA and 16 539 casualties, 5 607 persons injured, 600 fatalities and 253 ships lost was reported to EU investigative bodies (European Maritime Safety Agency, 2017). Between 2011-2016 cargo ships represent 47% of these casualties with ships, where 25% were loss of electrical power, propulsion power, directional control or containment. Loss of propulsion in in heavy weather or small passages can lead to dangerous situations and cause serious casualties on both ship and crew. (European Maritime Safety Agency, 2017 p.21 & 46). The investigational body of the United Kingdom *Marine Accident Investigation Branch* reports regarding the accident about the berth collision with the 332 meter long container vessel Savannah Express after a shutdown occurred on main engine during berthing operation, the vessel lost propulsion and drifted heavily into the link span at 2 knots in port of Southampton 2005. (Marine Accident Investigation Branch, 2006).

All kinds of non-conformities, accidents and hazardous situations shall be reported to the shipping company by following the ship safety management system manual procedure. The shipping company is required by the International safety management (ISM) code to provide a system through which these situations can be reported as well as used to arrive at lessons learned (The International Safety Management Code, 1998). One such system is IRIS, which can in extension be used to forward reports to the marine accident database "ForeSea".

1.1 Purpose

By compiling and investigating the everyday combustion engine, combustion engine control system and combustion engine peripheral system related accidents, incidents and near misses reported to the database "ForeSea", the purpose of this thesis is to map the possible areas of concern. This mapping could then be used by crews onboard Scandinavian owned ships to reduce the number of blackouts, losses of propulsion etc. caused by a problem directly surrounding a combustion engine.

1.2 Research question

Where do the causes for combustion engine failure reported to ForeSea, in the span 2007-01-01 - 2017-12-31, lie?

1.3 Delimitations

This study will only compile data from ships that have chosen to send reports to the database “ForeSea” and its predecessor “Insjö”. The ships in question are almost solely Swedish, Finnish and Danish flagged. This paper will furthermore be restricted to reports where the cause for the failure lies with a combustion engine, the combustion engine control system or its peripheral systems.

2 Background/Theory

2.1 Accidents

In the incident report regarding Exxon Valdez the vessel was operating in an high risk area with ice and refs. The officer of the watch did a late manoeuvring which caused a grounding and 258 000 barrels of cargo seeped into the water.
Another similar oil spill incident saw 4 000 barrels spread in a diameter of 6 000 yards, in 5 hours (National transportation safety board, 1990). Major accidents like these are a threat to the environment with an excess of 5 500 000 tonnes having been released from accidents and groundings, making up 9.8% of the yearly oil contamination of the seas (Andersson, Brynolf, Lindgren and Wilewska-Bien, 2016, p. 128-129).
One of the reasons for ships grounding are combustion engines stopping. The report regarding MT Braer blackout when the diesel fuel tank got contaminated, which resulted in the boiler stopping and the heavy fuel oil (HFO) cooling, so the engine crew decided to change fuel for both main and auxiliary engines from HFO to diesel. The engines still stopped and the ship lost the ability to manoeuvre and drifted to Shetland island and forcefully grounded. The hull was damaged and the crude oil carried in the cargo tanks leaked out into the water (Marine Accident Investigation Branch, 1993).

2.2 Systems

Diesel engines are the most common means for propulsion in the merchant fleet. The engine type is divided to three main categories: low-speed, medium-speed and high-speed engines. Other engines like steam turbines were used in another era and gas turbines are more common in high-speed ships (Rowen, Alan 2014). The main engine is equipped with auxiliary systems for cooling, lubricating and fuel oil supply etc. that are not integrated in the engine construction (Smith, Crawford & Moore, 2016 p1-19). On the auxiliary engines fuel, lubricating and HT pumps may be attached to the engine Smith et al. (2016 199-229).

2.2.1 Cooling water System

The cooling water system onboard normally consists of three parts: seawater (SW), low temperature water (LT) and high temperature water (HT) loops. The SW is cooling the LT via a central cooler which in turn is cooling the main engine scavenging air, lubricating oil, HT and the auxiliary machinery components like diesel generators and air compressors. The HT loop´s purpose is to cool the main engine to a temperature that fits the engine, normally set around 80 Celsius (Theotokatos, Sfakianakis & Vassalos, 2017).

2.2.2 Lubricating oil

The lubricating system is a circulating system. A lubricating pump drawing oil from the engine sump or a lube oil tank, through a strainer, to a cooler and then distributes it to the engine (Nitonye, 2017). On smaller engines lube oil is changed regularly to keep the lube oil clean. On bigger engines a treatment system is usually connected to the lube oil tank and oil-analyses are carried out to keep the oil in good condition (Kuiken, 2012 ch.11).

2.2.3 Fuel oil system

Before the fuel enters the engine, it passes several stages. First it should be placed in a settling tank, from the settling tank the fuel is normally transferred to a fuel oil day tank, via a purifier where solid particles are removed from the fuel (Kuiken, 2012 ch.24). In a standard system the fuel is pumped from the day tank to a mixing tank, through a pre-filter, then from the mixing tank via booster pump, heaters and fine filters before it enters the engine (Kuiken, 2012 ch.8).

2.2.4 Engine control system

For control of flows and temperatures in the systems above a pneumatic control valve is usually installed. The HT and LT water systems are mixed with a thermostatic valve for a preferable temperature that fits the engine. In lube oil systems a three-way control valve is installed to control the temperature and decide the amount of oil that should pass the lubricating oil cooler. In the fuel system the fuel viscosity is monitored by a sensor which sends information to the control valve for the heating medium at the exchanger and the mixing tank level is controlled. The mixing is a deaerating tank and the tank pressure is controlled by air and a control valve for reach correct pressure for the booster pumps need (Crawford, 2016 p.152-168)

2.2.5 Electrical supply onboard ships

There are different ways of generating of electricity onboard. Through the use of combustion engines, gas turbines, steam turbines or a steam and gas combination, via a propulsion shaft to a generator or a directly connected generator an electrical supply to the vessel can be achieved. The gas and/or steam turbine generator is usually driven by heat waste and depend on the exhaust energy from the ships engine. Even though there are options the most reliable way for a ship is to use diesel engines to supply the vessel (Kuiken, K 2012 ch.18)
The IMO convention SOLAS have requirements that the electrical supply shall consist of at least two generators and demand that one generator shall be able to supply the vessel during normal operation conditions. (SOLAS Including all amendments in force 1 January 2017> Chapter II-1 -Regulation 41- 1.1 & 1.2).
An error or a disturbance in a ships electrical system can cause a blackout. When this type of failure occurs the ship lights onboard disappear, and steering gear and propulsion arrangement can be lost. The time to solve a blackout can differ depending on how the electric distribution system is structured onboard the vessel. (Onnettomuustutkintakeskus, 2017). Normally when blackouts occur the emergency generator will start automatically and supply the vessel emergency systems via an emergency switchboard. (Pro electronica sur, 2010).

The gen sets are remotely controlled by a computer based system called the Power Management System (PMS). The main purpose of the PMS is to increase the reliability and prevent blackouts by collecting data from the vessels power grid and generators, make the auxiliary system more fuel efficient and monitor equipment to prevent unnecessary maintenance and failures. Using the PMS it is possible to decide how the load share between the generators shall be distributed by changing operation modes and priorities. The PMS is also equipped with an operation mode

where extra power can be supplied for preparing the start of heavier electrical consumers. (Jaleel, Devassy, Vincent, Rose & Raphel, 2016)
In the International Association of Classification Societies (IACS) *"Requirements concerning electrical and electronic installations"* they have divided electrical computer based system failure into 3 categories regarding the effect of a failure in computer based components. The PMS is in the highest risk level which can directly lead to dangerous situations for ships, people and the environment (IACS, 2016).

2.2.6 Shutdown

The machinery and electrical automation system shall include slowdown and shutdown functions monitoring components that can directly led to total failure of the engine and/or propulsion equipment (SOLAS > Chapter II-1 - > Regulation 31 - Machinery Controls, 2017). The classification society Det Norske Veritas (DNV) has rules for the classification of ships concerning the pre- warning and shutdown functions. For engines with total power of not less than 375 kW: in case of overspeed, explosive crankcase atmosphere in diesel engines or short-circuit in electrical propulsion plants the automation system shall do a shutdown of the faulty engine without the demand of pre- warning. In the case of alarms for other parameters, like lube oil pressure, that can cause a total breakdown of an engine a pre- warning alarm will buzz before slowdown and shutdown limit is reached (Det Norske Veritas, 2013). A failure in the engine transmitters or switches can result in incorrect data being sent to the automation system. The time to failure is usually unexpected and this is a disadvantage of transmitters and switches (McGeorge, 2013).

2.3 Components

2.3.1 Onboard environment

Locations where high vibrations occur increase the potential risk of damage to vulnerable equipment (Taylor, 2013). The machinery onboard creates vibrations and heat which are a big source of the noise and temperature in the engine room. Depending on load distribution in a three-engine marine power plant the average acceleration amplitude of AE 2, while shutdown, may vary with a multiple of two (Daifuku et al. 2016). If a component vibrates due to resonance, there might only be one solution: relocation (Taylor, 2013 p.5)
Temperatures onboard can differ vastly Exhaust from engines can reach 400 Celsius and fuel like LNG is stored around -161 Celsius. An atmosphere with risk for condensation or high humidity can create problems in certain equipment in the form of different types of corrosion (Taylor, 2013 p.5-6).

2.3.2 *Machinery planned maintenance system (MPMS)*

To have a software based maintenance system onboard is a requirement from the classifications societies. The purpose of the system is to prevent damage and breakdown of components by performing inspections, testing and maintenance of equipment (Akyuz & Celik, 2017). The software shall, among other things, include a maintenance interval of class related components and non-class related components, job descriptions and a history of previous jobs (DNV-GL, 2016)

2.3.3 Redundancy

The classification society Det Norske Veritas (DNV) have requirements for redundancy. If an active component that is necessary for the ships propulsion fails there should be a backup component so that normal operation can be re-established. Active components include E.g., all pumps, coolers, filters and motorised valves in the propulsion system (DNV, 2011). Vessel with one main engine is required to have a take me home device equipped achieve vessels safety (Poljak, Mandekić, Adum, & Slapničar, 2009).

2.4 Fuel

2013 77% of the consumed fuel worldwide were of the residual type HFO and the remaining fuel were different distillate fuels. The HFO often contains a high amount of sulphur, with a global mass content maximum of 4.5% and the worldwide average was 2.7%. The exception before 2013 was the Emission Control Area (ECA) where the maximum sulphur content by mass was 1% and was planned in 2015 to be changed to 0.l% (McGill, Remley, Winther, 2013). According to Ford (2010), the rise in oil price before 2010 resulted in a decrease of fuel oil quality. Poor quality of heavy fuel oil can both cause problems in the fuel oil treatment system as well as damage important engine components (Ford, 2010). For example, a high content of catalytic fines increases the wear on fuel pumps, fuel injectors, cylinder liners and piston rings which raises the risk for breakdown, Ford (2010). The International Organization for Standardization (ISO) 8217 is standard and has requirements about fuel quality for marine engines and boilers to reach a standard that fits the fuel system equipment and machinery to work properly, Ford (2010). It is accepted that residual fuel cause most fuel problems but distillate fuels have troublesome characteristics as well. One big problem is microbial growth, which can cause blockages or even oxidation of tanks, Ford (2010). Even if there is no initial problems with two fuel oils, if they are mixed incorrectly the resulting mix may partially separate or completely break down, Ford (2010).
To avoid poor quality there are possibilities to perform bunker sample analyses to ensure that the fuel is not off-specification, still a noticeable amount of companies chose not to test their bunker, Ford (2010). Odland claimed that in 2005 only 40-50% of all bunkerings were being tested. 10% of the tests DNV performed turned out be slightly off specification and 1% were seriously off specification (Odland, 2005).

2.5 Operator

In the recent years the crew has been reduced in all departments, while the monitoring systems have become more complex and cover more equipment. An engineer may today be alone on the watch and run a whole engine room by himself (Taylor, 2013 p.3).

2.5.1 Human factors

Horberry, Grech and Koester (2008) claim that the maritime industry believes human error to be the root of most accidents and that this view is shared by most other safety minded domains. They then argue, citing Dekker, that the individual is mostly not to blame, but the underlying systemic problems “... tools, tasks and operating environment” (Horberry, Grech & Koester, 2008, p.18).

In a journal article by Tinsley, Dillon and Cronin (2012) they claim, based on hurricanes preparations, cruising ships and deep-water oil drilling, that the type of thought process before a potentially dangerous situation affects how people prepare and act. If the mentality is influenced by previous near misses that lacked consequences, and the potentially bad consequences of the impending situation are not contemplated upon, people are more likely to take inadequate preventative actions (Tinsley, Dillon & Cronin, 2012).

2.5.2 *Onboard*

In the study, by Seif, Degiuli and Mufti (2003), about working the environment on vessels and how the free space in the working and living areas, onboard Iranian ships, has changed during years. Onboard three vessels, owned by the same shipping company, of differing year of keel laying but similar gross tonnage (1977, 1992 and 1998). The cargo capacity has increased while the crew living and working areas have been partially reduced or minimised to the bare requirements. The minimization of workspace will result in a worse ability to perform maintenance in a satisfactory way (Seif, Degiuli, & Mufti, 2003).
The work onboard is demanding on a person's physical health as a job on board can be hard to perform due to uncomfortable ergonomic positions, and environments with high temperatures, high humidity, a lot of vibrations and a lot of noise (The nautical institute, 1998).

2.6 Overarching principles

2.6.1 *The accident pyramid*

The accident pyramid is a well-accepted model for explaining the relationship between the degrees of severity of an accident (Accident-Incident-Near miss-Unsafe act) ranging from 1:300 to 1:600, depending on the field (Horberry et al. 2008, p.17-18, Meyer and Reniers, 2016, 3.3.1). “A number of studies have confirmed this pyramidal relationship
between the categories, with ratios varying according to the type of industry. If incidents and near-miss data are well understood, it can provide important clues to ways a system is able to recover and revert to a safe state.” (Horberry, Grech & Koester, 2008, p.17).

2.6.2 Safety

In “The importance of near miss reporting to further improve safety performance” (Jonesa, Kirchsteigerb & Bjerkec, 1999) it is claimed that several industrial companies have believed, since before 1999, that reporting of near misses should be a part of safety management ashore. They go on by showing a graph correlating the decrease of Norsk Hydros Losses of time to the number of near-misses both off-shore (1990-1997) and ashore (1985-1997). They further claim that preventing near misses and other deviasions instead of trying to stop major accidents, more directly, is a more effective solution Jonesa et al. (1999).

2.7 ForeSea

The following texts have been copied from foresea.org since it provides condensed, first-hand information of the purpose and goal of ForeSea:
“What is the purpose with ForeSea?
ForeSea has been created to improve **maritime safety**.
By analyzing the information in ForeSea Experience Data Bank the shipping industry may:
• decide on actions and improvements based on facts.
• disseminating information about dangerous conditions in the form of "Safety Alerts".
• compile lessons learned in the form of "Lessons Learned".
ForeSea has the ambition to capture the conditions that are normally not reported to the authorities. To make this possible ForeSea is administered by a third-party body and the reporter is protected by anonymity.
ForeSea will also make it easier for member companies to comply with the ISM Code requirements for internal reporting. This is done by the customized information system IRIS* is offered at subsidized rates.” (ForeSea, Unknown).

*An information system developed for use by individual shipping companies. “ (ForeSea, Unknown)

“What statistics can be created using ForeSea?
ForeSea is not intended to produce statistics. The form, focusing instead on gathering qualitative information about what is happening or may happen in ship operations, what is worth sharing with others and learn from.
No official statistics, except for the key figures are produced by ForeSea. Of course, bars and graphs are created by using the data contained in the experience data bank. Where these are made, however the aim is to identify any trends and in this way to control the direction of measures to enhance maritime safety.” (ForeSea, Unknown).

During telephone interviews and guidance with the curator, he has brought forth his suspicions that bigger accidents, where the state-run accident investigation branches get involved, do not get reported to ForeSea. He also believes that the decrease in reporting rate, seen in fig. 1, is a result of company Designated Person (DP) believing only situations that are of a high enough importance is reported (Curator, personal communication, April 25, 2018).

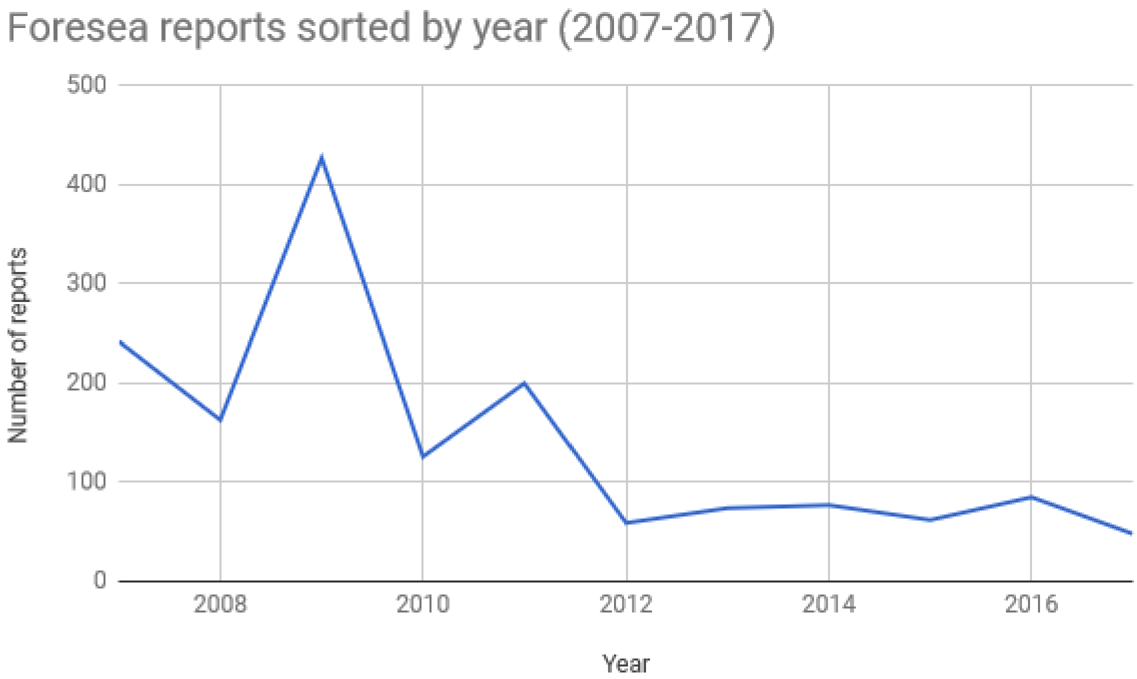


Figure 1. Total number of reports submitted to Insjö and ForeSea, sorted by year. Authors´ own copyright.

3 Method

3.1 Choice of method

The method that has been used is quantitative research methodology. By descriptive statistical secondary analysis of the ForeSea reports describing situations where combustion engines have shut down or disconnected from its system, without the crews’ intention and/or desire. This has simplified the process of finding and evaluating patterns.

3.2 Criteria for selection

The reports have been compiled by searches in the ForeSea database search engine. The authors have been assisted by the curator of ForeSea, who receives and anonymises all reports.
The date was set to *After 12/31/2006* and all reports filed after 12/31/2017 have been discarded
The phrases used for the searches have been:

- *blackout OR "blackout"*
- *Manoeuvrability OR propulsion*
- *"ME stop" OR "AE stop" OR "engine stop"*

The types of ships that have been excluded due to the authors´ their relatively low power output compared to other merchant ships:

- Passenger ship (SWEREF)
- Road ferry

For a report to be considered relevant to this thesis the following must be fulfilled:

1. A combustion engine, or several, must be disconnected from its task by a monitoring/regulatory system, because of the engines inability to provide the power and/or frequency required at the flywheel to maintain its function, without external human intent or fully stop without external human intent.
2. The underlying fault must be stated by the writer in the structure, mentioned as the cause in the free text or suspected by the crew, as the cause.

In the cases where another combustion engine shut down as a result of a reports prime focus, the resulting shut down was not included in the compilation, since the cause of the series of events lied with the first combustion engine.

3.3 Categories

The reports were separated into five categories or discarded. Three of these categories have subcategories. The categories are as follows:

Component includes incidents where the cause of the incident laid with a component of the engine or peripheral system, that the report does not state as ill maintained, installed incorrectly, used improperly, ordered improperly or have exceeded its service or operating hours according to ships MPMS or other documented procedure.

Mechanical: includes incidents where the cause of the incident stemmed from a purely mechanical component failure that causes a full stop or disconnection of an engine or engines.

Electrical: includes incidents where the cause of the incident stemmed from a mechanical failure in an electric component, improper electrical connection or a damaged wire that causes a full stop or disconnection of an engine or engines.

Sensor: includes incidents where the cause of the incident stemmed from the part of the sensor that monitors parameters and govern shutdown functions of an engine.

Operator includes incidents where the cause of the incident laid with a member or members of the crew or personnel assisting the ship.

Maintenance: includes incidents where the cause of the incident stemmed from improper maintenance or lack of maintenance.

Running Mode: includes incidents where the cause of the incident stemmed from improper use of machinery and peripheral system automated functions, outside of testing.

Test: includes incidents where the cause of the incident stemmed from improper actions, or lack thereof, in testing engines and peripheral systems

Uncertain includes incidents where the cause of the incident is not laid with a certain cause.

*P.C. = Two **P**ossible **C**auses:* Failure in a component with two possible causes but no concluded reason that caused the shutdown

Inv. Canc. = Investigation Cancelled: Responsible system is stated but information to pinpoint the cause as to why shutdown occurred is considered unavailable by the crew.

Inc. Info. = Incomplete Information: The cause given is of lesser quality than other reports, but still useful for evaluation.

Fuel includes incidents where the cause of the incident laid with engines running on fuel of lacking quality.

Automation system includes incidents where the cause of the incident laid with a computer based program that starts and/or stops machinery, determines the load distribution etc.

4 Results

Currently there are more than 3 200 reports in the ForeSea database, of which 52 reports match the selections and are therefore relevant to this study.
For a semi shortened version of our extended findings see appendix A.

4.1 Graphs

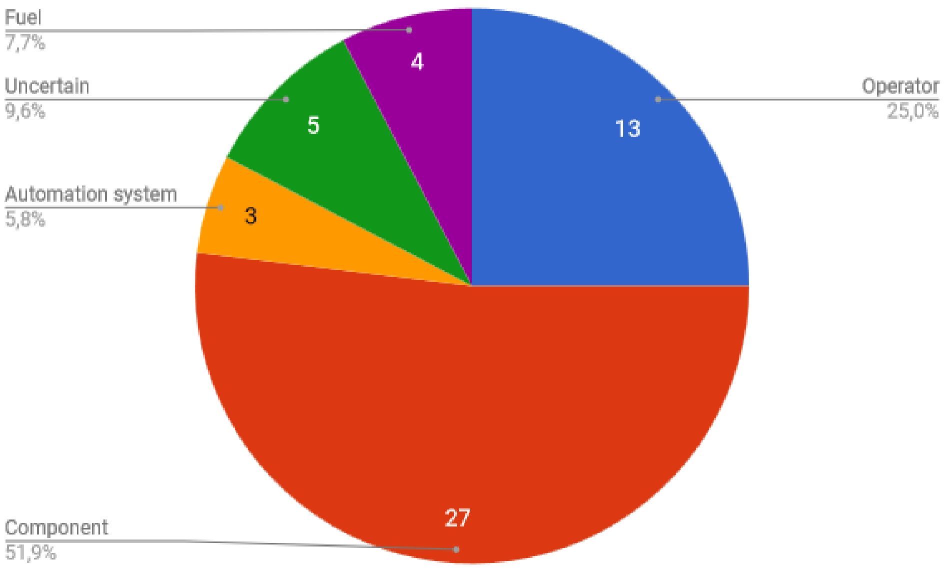


Figure 2. Number and percentage spread of categorised combustion engine failures. Author's own copyright.

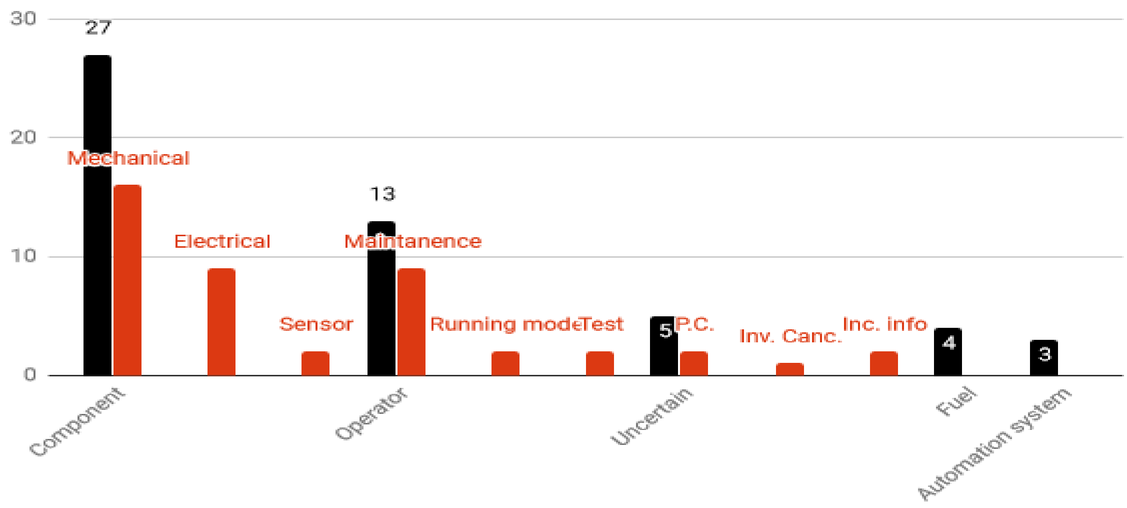
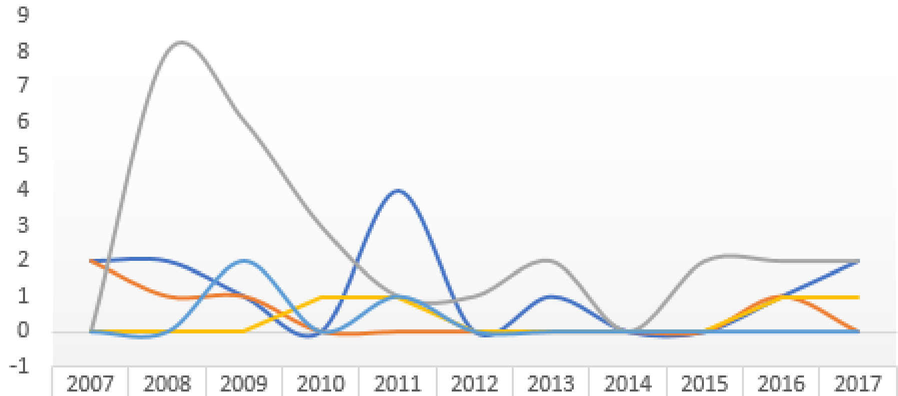


Figure 3. Number of combustion engine failures in categories and subcategories. Authors´ own copyright.



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Operator	2	2	1	0	4	0	1	0	0	1	2
Unknown	2	1	1	0	0	0	0	0	0	1	0
Component	0	8	6	3	1	1	2	0	2	2	2
Fuel	0	0	0	1	1	0	0	0	0	1	1
Automation system	0	0	2	0	1	0	0	0	0	0	0

Figure 4. Number of reports sorted by year and authors´ categorisation. Authors` own copyright.

4.2 Examples of categorising

Component

One example of Component>Mechanical is when a valve was broken in the fuel oil supply system and stopped the fuel to enter the engine.

One example of Component>Electrical is when a temperature bearing sensor on main engine had poor connection between sensor and cable which activated the shutdown function and stopped the main engine.

One example of Component>Sensor is when two auxiliaries were running and the speed transmitter on SB AE lost its function to monitor the revolutions in an auxiliary engine which resulted in disturbance in the main grid. BB AE stopped by operator and the faulty engine stopped after few seconds which caused a blackout.

Operator

One example of Operator>Maintenance is when a lubrication valve was not properly opened after a service, which led to a shutdown of the main engine.

One example of Operator>Running mode is when the load of main engine was reduced and the ship operating in shaft generator mode, which led to imbalance in the main grid, which in turn caused a blackout.

One example of Operator>Test is when an auxiliary engine was started by a crewmember for a test of shutdown functions while the shaft generator was connected. The auxiliary generator connected to the grid and the PMS decide to disconnect the shaft generator. The test was performed and auxiliary stopped, which resulted in that no generator was connected to the grid.

Uncertain

One example of Uncertain>P.C. is when the main engine stopped by a fault in the governor and they concluded two possible causes, maladjusted governor or bad cable connection.

One example of Uncertain>Inv. Canc. is when the engine stopped by high cooling water temperature of unknown reason, basic investigation done without any findings.

One example of Uncertain>Inc. Info is when the auxiliary engines stopped because of water from the fuel heating system entered the diesel tank. The cause is not mentioned but is implied.

Fuel

One example of Fuel is when a high-pressure fuel oil pump seized due to the fuel quality and stopped the main engine.

Automation system

One example of Automation system is when the lubricating pump to the main engine stopped by the automation system. The shutdown function was activated and stopped the engine due to low lube oil pressure.

5 Discussion

5.1 Operator

25,0% of the failures seem to have been caused by human error. However very little, if anything, is mentioned about the workplace mentality, tools, difficulty of maintenance etc. If this would have been more prominently included further examination could be undertaken, using Horberry et al. (2008) and Tinsley et al. (2012)s´ hypotheses. Three out of the thirteen reports propose that the cause of the accident lied with education or competence, whilst seven propose improvements to systems or improvements or creation of instructions onboard. Two of these are the same, which could imply that in five out of thirteen (38%) cases of human error, the individual is blamed (See appendix B), which would be in conflict with Deker´s teachings. Even though one can suspect that it is the case, reports do not clearly state that there could be a deeper cause that is connected to sociotechnical systems.

5.2 Component

The largest of all categories is components with 51,9% of the analysed reports. The requirements to be included in this category were that the report does not state the component "...as ill maintained, installed incorrectly or have exceeded its service or operating hours according to ships MPMS." A recurring theme in the reports is to not speculate, some do, but the majority is short on extra information. This is reflected in the chosen corrective measures as most reports state the component as broken/malfunctioning and then state the corrective measure. 48% of the measures merely restore the system to the previous shape, 30% introduce new or improved routines and 22% improve the ship or system and/or tools (See Appendix C). Despite not discussing many possibilities the crews seem to suspect, in 52% of the reports, there to be either a hidden root cause or general room for improvement (See Appendix C), maybe even along the lines of Taylor (2013), Seif et al. (2003) or Horberry et al. (2008). If this is the case, it could be argued that some of the reports could actually have been caused by human error whilst designing the systems or the ship. Further one could argue that even some of the crews that merely restored the systems/ships were unaware of existing sociotechnical systems which could have hindered their performance, shifting the cause from a component error to a human error.

5.3 Fuel

It has been impossible to determine if the problems have been caused onboard by improper procedure or during ordering according to proper/improper procedure. Fuel has been given its own category, instead of being included in *Uncertain>Incomplete Information* as they tuned out to be eight percent of the total number of reports.

Three out of the four fuel quality related failures had management: *Supervision/Responsibility* as their stated cause, one of which had Inspection/Test/Approval as a further explanation (this was interpreted by the authors as lack of fuel oil testing). Since this failure happened in 2016 Odland (2005)´s findings might still be relevant. The fourth failure stated *Quality of Materials/Equipment* and tells in the text that a request to increase the minimum quality requirement for fuel oil has been sent to the party responsible for ordering the bunker. In the text it is furthermore mentioned that the oil has been sent in for a full spectra analysis, since it is more reliable than a normal bunker sample analysis, while not stating if a bunker sample analysis has been carried out before the fuel was used. Combining Odland (2005)´s observations with Ford (2010) and the categorised failures, it is hard to say if the cause for the failures lies with those who order the bunker, those who store the bunker, the lack of fuel oil analysis, the quality of the fuel oil analysis or if the fuel oil market is delivering oil of lesser quality than ordered. In some of these cases it could be argued that our category *Fuel* could fall under the category *Operator*.

5.4 Automation Systems

Bugs in computer systems, regarding the failure rate of combustion engines onboard, seem to have a low frequency, with a wide spread of effect and should therefore not be the primary focus trying to eliminate incidents concerning combustion engines onboard ships, although for example IACS (2016) ranks the PMS in the highest risk category.

5.5 Accident prevention

ForeSea has seen a decrease in submitted reports compared to 2009 comparing the number of reports submitted to Forsea *Fig. 1. Total number of reports submitted to Insjö and ForeSea, sorted by year* to *Fig. 4. Number of reports sorted by year and authors´ categorisation* three out of the five categories show a decline somewhat matching ForeSea´s overall decline of reports and none show an increase. Combining this with the curator´s suspicions (Curator, personal communication, April 25, 2018) of the attitude towards incident reporting could mean that there has been an inverse Norsk Hydro effect (Jonesa et al. 1999) since then.
Since it has been hard to find scientific papers on premature component breakdown, and incidents surrounding operator error and possible human error exceed 25% we assume that a decrease in accidents such as MT Braer (Marine Accident Investigation Branch, 1993) can be accomplished, by the accident pyramid principle (Horberry et al. 2008, p.17-18, Meyer and Reniers, 2016, 3.3.1), by making the crew and management observant of the different sociotechnical systems onboard and between ship and shore or, if this is already is the case, include more descriptive information surrounding the incident.

5.6 Method discussion

Bryman and Bell propose the boons of secondary analysis to both students and the society. The public answers fewer interviews and questionnaires while students can reallocate funds and time whilst getting access to data with a high possibility of good quality. All they have to say about secondary analysis is not positive though. Bryman and Bell bring up matters such as unfamiliarity with and the quality of the gathered material and its structure, the complexity of using the material and possibility of a difference in purpose of the research team gathering the data and the team using the same data at a later date (Bryman & Bell, 2017 p. 307&312)
ForeSea gathers reports to advise the shipping business on maritime safety, which is in line with the purpose of this study and there should be no major problem in comparing accidents on ships over the last ten years. The authors of this paper both hold the certification of third engineer officer and thereby could be assumed to understand the events and components included in the

reports sent to ForeSea. The reports themselves have been varying in length and substance, making them less than easy to categorise, but there have been enough good reports to outweigh the possibly poor ones.

Reliability

All data available in the database has either been submitted directly to ForeSea or transferred from the predecessor “Insjö”. All data gathered has been collected by the same curator, using the same form “Insjörapport”, during the relevant years.
One of the writers was solely responsible to decide whether a report was relevant or not but the categorisation was a collaborative effort. At no point in the categorising one of the authors was solely responsible for categorising.
A small-scale test for internal reliability was performed. Spot checks of both accepted and categorised reports, and discarded reports were re-examined and found to be correct, even after the compilation.

6 Conclusions

The purpose of this thesis was to map the possible areas of concern. By investigating the causes that have led to combustion engine failure, reported to the incident database ForeSea. This was fulfilled through analysing, and answer question:
Where do the causes for combustion engine failure reported to ForeSea, in the span 2007-01-01 - 2017-12-31, lie?

According to the accidents, incidents and near-misses submitted to ForeSea the main cause of everyday combustion engine failure is a single unexpected component failure, though we have argued that some of the reports categorised as *Component* could have its root in human error, by the crew not knowing or realising that the sociotechnical systems could have affected the performance of the crew, resulting in a seemingly non-human error.

The second largest cause of combustion engine failure turned out to be operator failure during maintenance and careless acts. In the analysed reports categorized as operator 38% seem to indicate that the individual is to blame.

6.1 Future research

- What has caused the reporting to ForeSea to decrease?
- What effects could an increase of questions in the reports have?
- Do all reports submitted to ForeSea correctly follow the template, and if not how and why do they deviate?

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Appendix

Appendix A:

Categorysation by authors	ForeSea-ID	Year					
Operator (Maintenance)	2131	2011	No fuel	Engineer stopped wrong pumps to clean FO filters AE 3&4			
Operator (Maintenance)	2052	2011	setpoint for the L.O. Low Pressure incorrect setting	Maintenance / Repair Error			
Operator (Maintenance)	871	2008	Bel: (Corrosion) or (gap after maintenence) in govenor	Maintenance			
Operator (Maintenance)	845	2008	Overheating, Low level exp tank, Tacko alarm	Big end bearing OH>RPM down>load up>Blow by	Unfiltered oil	(Installation) Filling up newly serviced filter wrong	
Operator (Maintenance)	882	2009	Time relay start set to 0 after work	Poss: PMS	Poss: frequency drop		
Operator (Maintenance)	3288	2013	Low LO press	Valve not properly opened after cleaning lub. oil filter on main engine.			
Operator (Maintenance)	3117	2011	LOw LO press	LO filter loose	Bel: Metal chip in thread of filter		
Operator (Maintenance)	677	2007	UK stop	High exh temp & loss of charge air press	Crack in charge air bend & sheared screws	Bel: Incorr tightening	Installation
Operator (Maintenance)	801	2007	control system did not get any battery power	Breaker opened		Bel: shortcircuit troubleshooting water heater	
Operator (Running Mode)	3668	2017	ME running in incorrect mode	Individual Mental Action (Bridge/Wheelhouse)			
Operator (Running Mode)	3655	2017	ME running in incorrect mode				
Operator (Test)	2103	2011		Negative load on auto AE, whilst other AE at 700KW			
Operator (Test)	3591	2016	PMS hierarchy disconnected shaft alternator and AE shut down by ER personel	AE control left in auto	Bel: Forgetfulness/Human factor		
Fuel (Quality)	3688	2017	Lack of fuel qualities.				
Fuel (Quality)	3601	2016	clogged fuel discfilter direct on A/E.	Insufficient fuel quality.	Supervision/Responsibility		
Fuel (Quality)	3086	2011	Poor FO quality				
Fuel (Quality)	3036	2010	No/low fuel	Closed fuel valve	Forgot to open during change over HFO-DO	Pressured situtation	Poor fuel quality
Component (Mechanical)	3649	2017	quick closing valve on GO tank not fully open	Reliability of Components and Systems			
Component (Mechanical)	2170	2012	No fuel	valve in fuel oil system broke	Reliability of Components and Systems		
Component (Mechanical)	3431	2015	Exhaust valve came loose	Substandard Acts: Materials incorrect			
Component (Mechanical)	930	2009	AE 3 fell to 46Hz	turbo-charger mal-function	Reliability of Components and Systems		
Component (Mechanical)	2929	2009	boosterpress 0 bar	blocked flow	Faulty FO meter	Reliability of Components and Systems	
Component (Mechanical)	3576	2016	Dirty bronze filter	Poss: maintenace of oli mist detector			
Component (Mechanical)	839	2008	Low/no fuel	Air in DO system	worn o-ring inside an automatic fuel oil filter 14 days before service		
Component (Mechanical)	3303	2013	No/low fuel	Quick closing valves released	Pin holder broke	Vibrations	Bel: Press to high (Planned 7bar-5bar)
Component (Mechanical)	3432	2015	Poss: Overload	No fuel	Quick closing valves had closed	Bel: Root Cause: Equipment defective	
Component (Mechanical)	3035	2010	LOw LO press	LO pump broke down	24000/28000h inspection	MAN BW found nothing	Reliability of Components and Systems
Component (Mechanical)	1087	2010	High OM density	Watermist	Leaking mech shaft seal HT cool-pump	Reliability of Components and Systems	
Component (Mechanical)	1031	2008	Low LO press	LO pump break down	Pressure regulator pilote valve, unfiltered oil		Quality of Materials/Equipment
Component (Mechanical)	2964	2009	Govenor failuire	Low oil level	Boosterpipe nipple cracked	Reliability of Components and Systems	
Component (Mechanical)	2808	2008		HT exp tank low	Exhaust in HT	Cylinder head cracked	Reliability of Components and Systems
Component (Mechanical)	826	2008	Poss: Overload	low oil level in the governor	Loose pipe start boost-govenor	Vibrations	Reliability of Components and Systems
Component (Mechanical)	3679	2017		Burnt cables	Turbocharger waste gate gasket failed	Bel: Vibrations	
Component (Electrical)	3286	2013	Poor connections of ME bearing temperature sensors				
Component (Electrical)	3084	2011	Bel: Oil in side cable to sensor	Reliability of Components and Systems			
Component (Electrical)	994	2009	Bad electrical connection on a oil pressure gauge				
Component (Electrical)	1079	2010	Bel: Poor contact Electrical card	Reliability of Components and Systems			
Component (Electrical)	2810	2008	Overspeed	jumping rpm on indicator.	shild of pickup cable in contact in ME cabinet		Reliability of Components and Systems
Component (Electrical)	3602	2016	A broken bolt in a micro switch	Poss: lacking maintanence	Reliability of Components and Systems		
Component (Electrical)	859	2008	AE 3 fluctuating load	DO Boosterpump shut off	ESB powerless because Burned coil and loose li	Reliability of Components and Systems	
Component (Electrical)	2838	2008	Quick closing valves briefly closed	AE 2 quick closing indicator ground fault	Reliability of Components and Systems		
Component (Electrical)	2837	2008	Overspeed SHD	Govenor malfunktion	Electrical motor for actuator	Reliability of Components and Systems	
Component (Sensor)	2965	2009	Faulty speed transmitter	Reliability of Components and Systems			
Component (Sensor)	1028	2009	Faulty OM detector	Reliability of Components and Systems			
Automation system	954	2009	AE 1 low frequency	Poss: Bug in PMS	Reliability of Components and Systems		
Automation system	3132	2011	Low LO press	Lo pump stopped	Control system shut pump off (not desired)		
Automation system	2968	2009	Oil/watermist in crankcase				
Unknown, inclomplete information	816	2007	Overspeed	Elec. gov. unable to stab rpm	heavy sea condition	Reliability of Components and Systems	
Unknown, inclomplete information	1058	2009	Water in MDO	Disorder of Machinery/Equipment Functions			
Unknown, two possible	738	2007	ME rpm irregular	Bad cable connecton or incorr adj gov	Reliability of Components and Systems		
Unknown, two possible	856	2008	Crank case monitoring (Oil splash)	faulty PLC in Crank case mon cabinet &/or	sensor-connection cable on cyl. no 7	Maintenance	
Unknown, Investigation cancelled	3599	2016	Unknown CW temp error				

Categorysation by authors	Cause stated by ForeSea´s report	Measure stated by ForeSea´s report	Root cause stated by ForeSea´s report
Operator			
	Individual Mental Action/-	Information to the Crew/Safety Alert	Control Loss, Operation of Machine/Equipment
	Individual Mental Action/-	Repair Work/Cleaning up/Correction	Control Loss, Operation of Machine/Equipment
	Maintenance.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions
	Installation.	Alternate Operation & Development of Procedures/Routines/Checklists	Disorder of Machinery/Equipment Functions
	Ship/Equipment Design.	Improved Design/Construction/Materials	Disorder of Machinery/Equipment Functions
	Individual Mental Action/-	Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	Control Loss, Operation of Machine/Equipment
	Qualification/Competence/-	Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	Disorder of Machinery/Equipment Functions
	Installation.	Repair Work/Cleaning up/Correction	Failure of Materials/Equipment onboard
	Qualification/Competence/-	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions
	Education/Traning/-	Improved Design/Construction/Materials & Information to the Crew/Safety Alert	Disorder of Machinery/Equipment Functions
	Individual Mental Action & Supervision/Responsibility	Development of Instructions/Manuals & Information to the Crew/Safety Alert	Control Loss, Operation of Machine/Equipment
	Individual Mental Action/-	Changed Size/Compentence of Crew = More training in operating the MSB in manual.	Control Loss, Operation of Machine/Equipment
	Individual Mental Action & Supervision/Responsibility	Improved Methods/Procedures	Control Loss, Operation of Machine/Equipment
Fuel			
	-/Supervision/Responsibility.	Improved Quality Management	Failure of Materials/Equipment onboard
	-/Supervision/Responsibility Inspection/Test/Approval	Repair Work/Cleaning up/Correction & Improved Maintenance	Disorder of Machinery/Equipment Functions
	-/Supervision/Responsibility.	Improved Methods/Processes	Failure of Materials/Equipment onboard
	Quality of Materials/Equipment.	(Alternate Operation) & Survey/Inspection/Investigation	Failure of Materials/Equipment onboard
Component			
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Not Relevant
	Reliability of Components and Systems.	New Equipment/Tools & Improved Design/Construction/Materials	Failure of Materials/Equipment onboard
	Quality of Materials/Equipment.	Improved Methods/Procedures.	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Alternate Operation & Repair Work/Cleaning up/Correction	Disorder of Machinery/Equipment Functions
	Maintenance & Quality of Materials/Equipment	Repair Work/Cleaning up/Correction.	Failure of Materials/Equipment onboard
	Maintenance.	Repair Work/Cleaning up/Correction & Improved Maintenance	Disorder of Machinery/Equipment Functions
	Quality of Materials/Equipment & Ship/Equipment Design	Repair Work/Cleaning up/Correction, Limited Operation, Improved Design/Construction/Materials & New Equipment/Tools	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Improved Maintenance	Failure of Materials/Equipment onboard
	Quality of Materials/Equipment.	Repair Work/Cleaning up/Correction & Improved Design/Construction/Materials	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Improved Maintenance	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Disorder of Machinery/Equipment Functions
	Working Conditions & Reliability of Components and Systems	Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	Disorder of Machinery/Equipment Functions
	Ship/Equipment Design.	Repair Work/Cleaning up/Correction & Improved Design/Construction/Materials	Failure of Materials/Equipment onboard
	Maintenance.	Repair Work/Cleaning up/Correction & Improved Maintenance	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Improved Design/Construction/Materials	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Improved Maintenance	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Improved Maintenance	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Alternate Operation & Repair Work/Cleaning up/Correction	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Improved Design/Construction/Materials.	Failure of Materials/Equipment onboard
	Reliability of Components and Systems.	Alternate Operation & Repair Work/Cleaning up/Correction	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction.	Failure of Materials/Equipment onboard
Automation systems			
	Reliability of Components and Systems.	Alternate Operation & Improved Design/Construction/Materials	Disorder of Machinery/Equipment Functions
	Ship/Equipment Design.	Improved Design/Construction/Materials	Failure of Materials/Equipment onboard
	Not Relevant.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation (Missguiding)	Control Loss, Manoeuvre of the Ship
Uncertain			
	Water-Sea State/Current/Ice & Reliability of Components and Systems	Alternate Operation & Improved Design/Construction/Materials	Disorder of Machinery/Equipment Functions
	Maintenance.	Improved Methods/Procedures	Disorder of Machinery/Equipment Functions
	Reliability of Components and Systems.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions
	Maintenance.	Repair Work/Cleaning up/Correction	Disorder of Machinery/Equipment Functions
	Not Relevant.	Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	Disorder of Machinery/Equipment Functions

Appendix B

Measures *Operator*			
Information to the Crew/Safety Alert	1		
Repair Work/Cleaning up/Correction	1		
Repair Work/Cleaning up/Correction	1		
Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	1		
Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	1		
		5	0,384
Improved Design/Construction/Materials & Information to the Crew/Safety Alert (Susspected as miss-labelled)	1		
Changed Size/Compentence of Crew = More training in operating the MSB in manual.	1		
Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	1		
Development of Instructions/Manuals & Information to the Crew/Safety Alert	1		
Improved Methods/Procedures	1		
Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	1		
Alternate Operation & Development of Procedures/Routines/Checklists	1		
		7	0,538
Improved Design/Construction/Materials	1		
		1	0,076
	13	13	

Appendix C

Measures *Components*			
Restoring Mesures			
Repair Work/Cleaning up/Correction.	8		
Alternate Operation & Repair Work/Cleaning up/Correction	3		
Repair Work/Cleaning up/Correction & Survey/Inspection/Investigation	2		
		13	0,481
Improveing the ship or system and/or tools			
Repair Work/Cleaning up/Correction & Improved Maintenance	5		
Improved Methods/Procedures.	1		
Repair Work/Cleaning up/Correction & Development of Procedures/Routines/Checklists	1		
Repair Work/Cleaning up/Correction & Improved Maintenance	1		
		8	0,296
Introducing new or improved routines			
Repair Work/Cleaning up/Correction & Improved Design/Construction/Materials	3		
New Equipment/Tools & Improved Design/Construction/Materials	1		
Repair Work/Cleaning up/Correction, Limited Operation, Improved Design/Construction/Materials & New Equipment/Tools	1		
Improved Design/Construction/Materials.	1		
		6	0,222
	27	27	1