The biggest challenges with autonomous costal ferries

And the benefits with sailing autonomous

Bachelor thesis in Marine Engineering

Anton Eriksson
Sebastian Gevriye

Department of Mechanics and Maritime Sciences
Chalmers University of Technology
Gothenburg, Sweden 2018

BACHELOR THESIS 2018:40

The biggest challenges with autonomous costal ferries

And the benefits with sailing autonomous

Bachelor thesis in Mechanics and Maritime Sciences

Anton Eriksson

Sebastian Gevriye

Department of Mechanics and Maritime Sciences
Bachelor of Science in Marine Engineering
CHALMERS UNIVERSITY OF TECHNOLOGY

Gothenburg, Sweden 2018

The biggest challenges with autonomous costal ferries

And the benefits with sailing autonomous

ANTON ERIKSSON
SEBASTIAN GEVRIYE

Bachelor Thesis 2018:28
Department of Mechanics and Maritime Sciences
Chalmers University of Technology
SE-412 96 Gothenburg
Sweden
Telephone: + 46 (0)31-772 1000

Printing /Department of Mechanics and Maritime Sciences
Gothenburg, Sweden 201

The biggest challenges with autonomous costal ferries

And the benefits with sailing autonomous

ANTON ERIKSSON

SEBASTIAN GEVRIYE

Department of Mechanics and Maritime Sciences
Chalmers University of Technology

Sammanfattning

Målet med detta arbeta är att hitta de största utmaningarna med autonoma färjor och vad fördelarna är med att segla autonomt. Materialet som har använts för att få fram resultatet är olika typer av artiklar, böcker och intervjuer.

Denna studie undersöker problemen som kan hända under operationen av ett autonomt fartyg. Denna studie är baserad på fallstudie, intervjuerna var utförda med olika personer som har god kunskap och bakgrund om autonoma fartyg, studien fokuserar på problem med autonoma fartyg.

Resultatet av studien och intervjuerna indikerar att en av flera problem med autonoma fartyg är nät säkerhet, bandbredd, regelverk och övergångsfasen. Trafikverket har cirka 70 närgående färjor, tre passagerare båtar och en svävare. Trafikverket har inga planer just nu på att bygga eller lansera några nya autonoma fartyg men dom är öppna för diskussion om att använda autonoma fartyg för några av deras mindre rutter om tekniken utvecklas mer.

I denna studien har vi hittat att det finns få fördelar med att segla autonomt i dagens läge, men vissa av fördelarna kan ses som minskat utsläpp av skadliga ämnen som i sin tur minskar bränslekonsumtion och att ta bort den mänskliga faktorn från fartyg.

I dagsläget så finns det inga stora fullt autonoma fartyg, fartygen som testas just nu i olika delar av världen är endast semi autonoma vilket betyder att det fortfarande finns manskap ombord fartyget utifall nått skulle gå fel.

Nyckelord: Autonoma kustfärjor, Kommandocenter, Nätverkssäkerhet, Bandbredd, Regelverk, Övergångsfas, Semi autonoma fartyg.

Abstract

The aim of this research is to the biggest challenges and benefits with autonomous costal ferries. The material used to get the result is varies articles, books and interviews.

This thesis addresses the problems that may accrue when operating an autonomous ship. The study is based as a case study, interviews were carried out on different people that are well understood and has great knowledge about autonomous ships. The study focusses on the problems with autonomous ships.

The result of the study and interviews indicates that when operating an autonomous ship, one of the few problems is cyber security, bandwidth, regulations and the transition phase. Trafikverket have around 70 costal ferries, three passage boats and one hovercraft. Trafikverket does not have any plans now to build and operate any autonomous ships but they are open for a discussion to use it on small coastal ferries if the technology develops.

In this study we have found that there aren't that many benefits of sailing autonomous ships in today's society, but there are some benefits that can be seen as reduced emissions from ships and in turn this means reduced fuel consumption and removing the human factor from ships.

Today there are no large commercial autonomous ships, the ships that are being tested and developed are semi-autonomous which mean that there is still a crew onboard if something goes wrong.

Keywords: Autonomous costal ferry, Operation center, Cyber security, Bandwidth, Regulations, Transition phase, Semi-autonomous ship

Foreword

The authors would like to thank Yemao Man, Margus Pöldman, Henrik Tunfors and Monica Lundh that has taken part in interviews and the companies that has shared information to help contribute to the assignment.

Also, we are very thankful to our mentor Magnus Hellman at Chalmers university of technology that has been of great support during the working progress of this thesis.

Table of Content

Image list

Definition

To help the reader understand important words and phrases that are mentioned in the report will be explained in this glossary.

ECR	Engine control room, a room where the crew can operate, get readings and to adjustments on the engine and the surroundings.
UMS	Unmanned machinery spaces, after working hours the engine room is unattended. There is one person that is on call every evening and night if any problems accrue in the engine room.
DNV	Det Norkse veritas, an international classification society and accredited registrar.
E0	E0 is a type of classification when running a unmanned machinery spaces, the ship needs to meet these regulations to be able to sail with unmanned machinery.
CCP	Controllable pitch propeller, a propeller with adjustable raising of the propeller blade.
DP	Dynamic positioning, automatic control of a unit or the ships position with the use of the ships propulsion system.
ME	Main engine, the main propulsion system that moves the ship forward.
SG	Shaft generator, a generator that is connected to the main engine that produces electricity when at sea.
AE	Auxiliary engine, produces electricity onboard the ship when the shaft generator not connected.
K-chief 600	K-chief 600 is a system designed to enable continuous accesses to primary vessel data onboard the vessel and ashore.
AIS	Automatic identification system, sends out information about a specific ship route, position, size etc. which all ships equipped with AIS can see.

1 Introduction

In the beginning the machine-driven ships were primitive. The first machinery ships were driven by steam and had constant watch going engine personnel to check and maintain the engines. (Hills, 1989) In time the ships developed to have diesel engines onboard but still had people checking and maintain the engine manually (Curley, 2012).
When the engine control room (ECR) was established the engine personnel were able to get the readings from the engine room directly to one place. This technology evolved to more advanced system with tanks, temperatures and pressure readings, etc. The regulation that are in use today is called unmanned machinery spaces (UMS) and is mainly in use on cargo ships, tankers and smaller ferries (International Maritime Organization, 2004).
Today it has become more normal for ship buyers to want the latest technology available when building new ships (Kumar, 2015). The advancement in technology is the key to one day having autonomous ships (Kumar, 2015), Extension alarm system for machinery spaces (Daekeun, Deokhwan, Jinho, & Dongho, 2016) also called EAS and UMS (Mohit, 2016) are the first steps toward an autonomous machinery spaces were the majority of the equipment onboard the ships are autonomous or remotely controlled from a control room, UMS and EAS system starts to eliminate the need for human errors and the need for Manned Machinery Spaces.
According to Det Norske Veritas (DNV) the engine crew works normal hours 8-17 (DNV, 2011) and after that they split the engine calls. If a problem occurs in the engine room they receive an alarm to their cabin, with this information they can decide if he or she needs to go down to the engine room to handle the problem. E0 is a type of system that helps the Marine engineer on call, it's a part of the UMS system (DNV, 2011) that alerts the watch caller when an alarm or reading malfunctions occurs so that the engineer on watch is notified and can handle the problem. E0 is a part of the UMS and EAS system for Unattended Machinery spaces (DNV, 2011) and Extension alarm system for machinery spaces (Daekeun, Deokhwan, Jinho, & Dongho, 2016).
The combination of E0, UMS and EAS is just the first step into autonomous engine room, when E0 is chosen to monitor the system it can detect faulty conditions in an equivalent satisfactory manner and handle the problems (DNV, 2011).
A few large companies such as Rolls Royce, Kongsberg and Google are starting to do research in autonomous ships (Prince, 2017). At the moment there are no commercial autonomous ships in service. The challenge with autonomous ships is that the regulations and technology does not exist, so these few companies that have started to investigate autonomous ships will lead and guide this technology (Prince, 2017).

1.1 Purpose

The purpose of this thesis is to look at the challenges with autonomous ships and see if it possible to sail a fully autonomous ship and what the benefits would be with sailing fully autonomous.

1.2 Questions

Main question:
What would the main challenges be with sailing an autonomous ship?

Sub question:
What would the two main benefits be to sail an autonomous ship?

1.3 Delimitations

This study will be focused on a small group of researchers and other people knowledgeable in the field of autonomous ships. Deeper understanding of how an autonomous ship works and is built as wells as the cost of building an autonomous ship won’t be included in this thesis.

2 Background and theory

Norwegian operators Fjord1 are planning on commission a fully autonomous and electrical ferry in 2018 (WIJNEN, 2017). Ferry is a type of ship that transports humans back and forward between two harbors (Nationalencyklopedin, 2010). The main difference between a car ferry and a passenger ferry is that the car ferry is usually several times bigger and can hold up to several hundred cars and lorries as well as passengers at the same time (Nationalencyklopedin, 2010). Ferries have always been thru time the most important mean of transportation (Nationalencyklopedin, 2010). Fjord1 new ferry will sail between Anda and Lote which is a 2.4km long route on the west coast of Norway (Pike, 2017) The ferry will be able to hold 120 cars and 12 trailers with the capability to carry 349 passengers (Pike, 2017). Fjord1 has also ordered an additional three smaller ferries with a length of 66m and a beam of 14m for a different route that will be able to carry 50 cars, 6 trucks and 195 passengers (Pike, 2017). The area of use will just keep on increasing for automatous ferries, the automatous control system has garnered a lot of interest from other areas both from big and small ferry operators across the world (Pike, 2017).

Autonomous ships could also be called artificial intelligence (AI) Ships, these are ships that are sailing with a form of artificial intelligence and being controlled by its own artificial intelligence (Nationalencyklopedin, 2010). The purpose of artificial intelligence is a human made way to resemble the brain with the ability to make their own decisions, plan, solve problems, acquire new knowledge, understand commands, language and so on. Artificial General Intelligence (Strong AI) is seen as having the same type of intellectual capacity as a human (Nationalencyklopedin, 2010).

An automounts car ferry would be a ferry equipped with a (COLREGS) maritime anti-collision regulations system (Jinfen, Xinping, Xianqiao, Lingzhi, & Di, 2012) as well as many other systems for example a type of DP system, DP (dynamic position) system (Wang, Li Hong, Miao, & Bian Guang, 2014). The advantages of an autonomous and unmanned ferry are many, but primarily centered on the reduction cost of production and operation (Phaneuf, 2016).

2.1 Propulsion systems

To give an insight into to propulsion system of a ferry and how it works in general and how its designed, it will be described here in three short sections of propulsion systems for a ferry.

2.1.1 Diesel Mechanical Propulsion System

A classic propulsion system for a ferry with conventional diesel mechanical propulsion system consist of two CCP- propellers with constant revolutions per minute (RPM) that are driven by diesel machines (Torstein, 2016). CCP – Controllable Pitch Propeller means that the rising on the propeller blade is adjusted after the propellers power demand while the propeller is rotating at a constant RPM (Torstein, 2016). Using a CCP propeller gives the ferry very good maneuverability, the ferry can move in all directions at a constant speed without the machines having to change their RPM or directions of rotation.

The propeller and propeller axel are either driven with one or two diesel engines thru a reduction gear. The axel generator is normally connected to the reduction gear, according to (Herdzik, 2013) Its normal that two diesel engines of different sizes thru a reduction gear are driving the same propeller axel. In total there are two bigger and two smaller diesel engines in the same ship, this in turn gives the ship operator the possibility to adjust the effect after consumption so that the diesel engines can work after optimal load (Herdzik, 2013). This means that when the load for example is around 60% two smaller diesel engines can be used, if the load is larger, around 80 % then the two bigger diesel engines can be used and if the demand is 100% all 4 engines can be used at the same time.

Other components in a propulsion system are generators, thrusters, auxiliary engines (AE) and emergency generator (EG). Thrusters contribute to increased maneuverability and the ability for the ship to stay in the same position. Electrical production for the thrusters and different electrical equipment are generated either by the axel generators or the auxiliary engines. In operations mode demanding a lot of power can both the auxiliary engines and emergency generators can be operated at the same time (Valkeejärvi, 2006). Diesel mechanical systems are effective on high load, this is built on a proven technique and has a reality low cost (al., 2017). The mechanical transmission losses are around 2-3% and it mostly in the reduction gear the losses accrue (Herdzik, 2013).

2.1.2 Diesel Electrical Propulsion

Since the 1990s has ferries started to be installed with diesel electrical propulsion. The technology has evolved a lot during the past years and today exist a row of different diesel electrical systems on the market. Diesel electrical systems increase fuel efficiency and then in a way decreases it effect on the environment. Other advantages with diesel electrical propulsion is that the ships engine room design is simplified, areas onboard can be used more efficient and the working environment in the engine room is improved (Valkeejärvi, 2006). The possibilities increase with diesel electrical propulsion as the electrical power technology evolves all the time. Components become smaller, cheaper and gets more functions (Torstein, 2016).

Diesel electrical propulsion has a few fundamental differences towards diesel mechanical propulsion. In a diesel electrical system, the propeller axel is not driven directly by the diesel engines they are instead driven by an electrical motor, a propeller engine (Valkeejärvi, 2006).
The power to the propeller engine is generated by number of diesel generators adapted after the ships size and electrical consumption. The power is then transferred from the generators to the propeller engines thru the ships electrical network. The most commonly used diesel engine onboard a diesel electrical ship is a four-stroke engine (Valkeejärvi, 2006).
As the power is transfer from the diesel engines to the propeller motors thru high voltage cables there is no need for a reduction gear or a propeller axel which in turn saves weight and important space in the engine room. This increases the working environment and safety of the engine room by not having to place the engines in the same room (Valkeejärvi, 2006).

The biggest advantages with diesel electrical operation is the flexibly and redundancy, with diesel electrical operation it is possible by frequency controlling the propeller engines to regulate the propellers rpm (Valkeejärvi, 2006). The amount of produced power can then be better adjusted after the need, this is done by turning off the diesel engine generators that aren't needed during operation and the remaining engines online can working near their optimal load where the fuel consumption is at its lowest (Valkeejärvi, 2006).

Even though increased flexibility, increased safety and decreased fuel consumption at lower and medium loads there are faults with diesel electrical systems. Transfer lost are relatively high in a diesel electrical system with a normal lost around 10%. The losses are mostly the fault of the generators, transformers, inverters and propeller engine (Herdzik, 2013).

2.1.3 Diesel Hybrid Propulsion System

Diesel hybrid systems are in fact a combination of diesel electrical system and diesel mechanical system that creates a powerful and flexible propulsion system that uses both technologies (MAN Diesel & Turbo).

In a hybrid system the propeller axel is driven in a similar way as in the diesel mechanical system, but the difference is that there is a diesel engine and a frequency controlled electrical engine connected to a reduction gear instead of two diesel engines (MAN Diesel & Turbo). The two propeller axels can be driven by only the mechanical system or the diesel electrical system or a combination of both this gives the system three different operation modes (MAN Diesel & Turbo). This gives the system high characteristics for high efficiency on lower loads, higher efficacy then diesel electrical systems on full load, low idling losses, high flexibility and high redundancy. But this in turn leads to greater cost in installment then both a diesel electrical system and diesel mechanical system (MAN Diesel & Turbo).

2.2 Engine Types

There are different types of Diesel engines and they can have a different number of cylinders (Nationalencyklopedin, 2010). In a straight-line diesel engine are all the cylinders of the engine built on the same row, in a V-engine are the cylinders in two rows that are aimed away from each other so that it resembles a V hence for the name of V-engine (Nationalencyklopedin, 2010).

2.2.1 Combustion and Diesel Engine Types

In this section different kinds of engine types and engine speed will be presented.

Four-stroke

The most common combustion method in a Diesel engine is the four-stroke method. The four-stroke method works in the way of combustion a mix of fuel and air, this means that the engine works in four steps.

- Step 1, The air valve opens, and air is sucked into the cylinder as the piston goes down.
- Step 2, The air valves is closed, and the piston starts to rise compressing the air, when the piston is close to the top position fuel is sprayed in and mixed with the air, due to the high air pressure inside the cylinder the air and fuel mixture self-combust.
- Step 3, The hot exhaust gas starts to expand and push the piston down.
- Step 4, The exhaust gas valve is opened, and the exhaust gases are pushed out by the piston and the whole processes starts over again.

(Nationalencyklopedin, 2010).

Two-stroke

The two-stroke engine is very similar to the four-stroke engine in the different steps but does it in two steps instead.

- Step 1, The piston moves from its upper position to its lower position to let a fresh air and fuel mixture enter the combustion chamber.

- Step 2, The piston starts to move up after reaching its lowest point and start to compress the air and fuel mixture, while the piston is moving up the inlet port for the air fuel mixture is closed, as the piston start to compress the air and fuel mixture it self-combust due to the high pressure inside the cylinder and the piston is pushed down and the exhaust gases are pumped out and then whole processes starts over.

(Nationalencyklopedin, 2010).

Slow speed engines

There are a few manufacturers that produce slow speed engines, the speed of the engine varies between 60-160 rpm and is always a crosshead type and a two-stroke. The engine output varies from 4,35-72,24 kW (Draffin, 2012).

Medium speed engines

The medium speed engines have a power output that ranges from 1,290-21,60 kW and the speed is between 450-1000 rpm. These kinds of engines operate using the four-stroke principal and are a trunk piston kind type of engine (Draffin, 2012).

High speed engines

The fastest engine types use the four-stroke principal and are a trunk piston engine. The power output varies between 150-2,350 kW and revs 1200-2500 rpm (Draffin, 2012).

2.3 DP-Dynamic Positioning

In a dynamic positioning system there are several components and systems working together to maintain a chosen position or direction (IMO, 1994). The DP classification describes three different classes that are divided up depending on the sanction of the fault and what type of fault that is considered. The classes are defined after how large the redundancy of the systems onboard the ship has.

For DP-classification 1, the propulsion systems don't need any form of redundancy and at an isolated fault the position can be lost (IMO, 1994).

For DP-classification 2 shall the propulsion system be able to split into at least two different systems incase an isolated fault of the system or active component happens the other systems should still be functional, and the positioning or direction shall still be maintained. During maneuvering procedure, its allowed to run propulsion as one system, but it must be able to automatically divide itself into two separate systems in case any types off fault such as a short circuit or an over charge happens which can be transferred between the systems and produce a blackout. This procedure will still be done by a remote switch on the electrical switchboard that in turn makes the system dividable (IMO, 1994).

For DP-classification 3 shall the propulsion system be able to split into at least two different systems incase an isolated fault of the system or active component happens the other systems should still be functional, and the positioning or direction shall still be maintained. Normal static components are still liable for faults. The propulsion systems must be placed in different compartments with protection against fire and flooding (IMO, 1994).

Active components or systems include the switch board, generators, thrusters, remotely controlled valves etc. Normal static components include cables, Manuel operated valves, pipes etc. that aren't fully documented with the aspect of safety and reliability (IMO, 1994).

2.5 Engine Room Layout

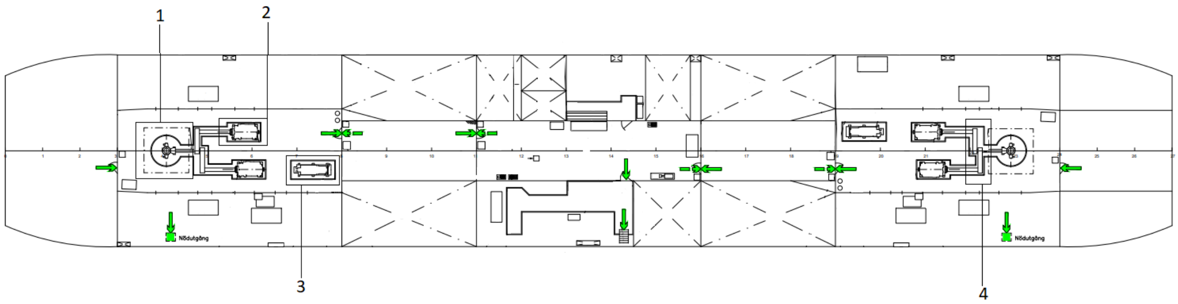

Figure 1. Engine Room Layout of a Typical Ferry (Trafikverket, 2017)

This is a typical ferry that operates in Sweden, it is 91 meters and carries 397 passengers and 75 cars (Trafikverket, 2014).

1. Azimuth thruster, propeller attached to a pod that can rotate 360°.
2. Main engine, two main engines on each side that produces the propulsion power.
3. Auxiliary engine, one on each side producing the electricity onboard.
4. Gear box transfers the power from the main engine to the Azimuth.

2.6 Innovations in Autonomous Ships

Kongsberg are involved in several projects that focus on autonomous ship. (KONGSBERG, u.d.) One project is the YARA Birkeland project where Kongsberg is responsible for all key enabling technologies including the sensors and integration required for remote and autonomous operations, in addition to the electric driven battery and propulsion system (KONGSBERG, u.d.).

The YARA Birkeland ship is supposed to be ready for operations late 2018 and at first will have a crew onboard operating the ship towards the year of 2019 the ship is supposed to start with remote operation and expected to perform fully autonomous operations by the year 2020 (KONGSBERG, u.d.).

China has also come out with a “smart” ship named Great Intelligence (Lakshmi, 2017).

The ship has a China-Developed system named SOMS which is a marine system with autonomous leaning ability and intelligent operation system. The system SOMS can analyze real-time navigation and meteorological data, pick the best routes and alert the crew to hidden dangers in advance (Lakshmi, 2017).

2.7 Self-sustaining System – Engine Automation

When looking at small coastal traffic to large container carriers they mainly use remotely controlled and operated systems. The data collected from the different systems are stored so that if a problem accrue it will be easier to solve it by looking at the history. Data can also be sent to the manufacturer and if they find a problem a new updated version can be sent to the ship (Kuiken, DIESEL ENGINES II, 2012, s. 222).

All-important speeds, loads, temperatures, pressures, liquid levels, etc. are measured. All these systems are fitted with different kinds of alarms. First there is a pre-alarm if not proper measures taken there will be a second alarm which can take pre-programed measures such as slowdown or shutoff. Many ships have alarm on all their auxiliary systems such as starting air, cooling water and lubricating oil (Kuiken, DIESEL ENGINES II, 2012).

The K-chief 600 is a system designed to enable continuous accesses to primary vessel data onboard the vessel and ashore (Kongsberg, 2014). The K-chief provides a safe, uniform, intuitive user interface, enabling operators to develop professional skills in system operation meanwhile reducing the risk of human factors.

The K-chief can also autonomously control different process plants and machinery systems in the engine room.

K-chief is also able to comprehensive self-diagnostic reports any malfunctions such as system component fault, communication fault, instrument fault and earth leakages (Kongsberg, 2014). The K-chief automation system is highly flexible providing competitive solutions for all types of vessels. The concept covers the whole range of basic alarm systems for unmanned machinery are operation, to fully integrated automation systems for machinery, propulsion and cargo operations (Kongsberg, 2014).

2.8 Communication Between Ship and Land

Safety is always a major concern since the loss off Titanic and the first SOLAS convention in 1914. Today ships are becoming more and more dependent on digital communication to operate efficiently (Jan & Beate, 2009). For an unmanned ship to operate efficiently it need to be equipped with advance sensor system to detect and avoid obstacles, a positioning and navigation system to determine and control exact location, speed and course as well as route, and the engine would also need advance on board control system to operate the ship and its equipment (Plass, Clazzer, Fritz, Yasrine, & Maurizio, 2014). This means that autonomous ships would be dependent on satellite communication when out of range of costal systems and this is a problem with cyber security (Housen-Couriel, 2016). Cyber security threats to satellite communications are a new phenomenon, but quickly come to be an important concern for the sustainability of satellite systems because of the vulnerabilities that such threats may be exploited and cause a negative impact (Housen-Couriel, 2016).

2.9 Safety

Appendix 1.

2.9.1 Regulation 26 General Regulations Regarding Machinery Installations

General regulations regarding the machinery installation for safety.

The machinery, boilers and other pressure vessels, associated piping systems and fittings shall be of a design and construction adequate for the service for which they are intended and shall be so installed and protected as to reduce to a minimum any danger to persons on board. (IMO, 1994)

See Appendix I for more information.

2.9.2 Regulation 40 General Electric Installations

All electrical auxiliary services necessary for maintaining the ship in normal operational and habitable condition will be ensured without recourse to the emergency source of electrical power.

See Appendix II for more information.

2.9.3 Regulation 46 Additional Requirements for UMS

The arrangement provided shall be such as to ensure that the safety of the ship in all sailing condition, including maneuvering, is equivalent to that of a ship having the machinery spaces manned.

See Appendix III for more information.

3 Method

This thesis refers to examine different people's opinions regarding autonomous ships and how the understanding of these ships will work (Höst & et al., 2006). To achieve an overview and comprehensive objective is the choice methodology an important factor. Because the purpose of this thesis is to research opinions has a qualitative case study been used. The method that has been used is to get as detailed and assorted answers to the questions at issue as possible. According to (Höst & et al., 2006) case studies considered to be a flexible methodology because it can be applied continuously after changed circumstances during the working progress. To get as detailed and assorted answers has several people knowledgeable about the subject been interviewed.

3.1 Data Collection

The data has been collected by reading suitable literature for the background and having interviews with people how are well understood in the subject, by doing this the questions were answered.

3.1.1 Background Material

To get a good understanding and knowledge about the subject the material has been collected and compiled by the studied questions. Scientific articles have been gathered from Chalmers database and relevant literature have also been studied to get a deeper understanding about the subject. During the search of information, we have prioritized the literature, so it's based on scientific grounds. Since the sources have different credibility it's very important according to (Höst & et al., 2006) that they are valued carefully. With a source-critical point of view, the articles that were most relevant for the study were chosen.

3.2 Interviews

To be able to get answer for the questions interviews were carried out on accouple of persons that are well understood in the subject and have great knowledge about it. By using a semi structured interview, the persons that gets interviewed can elaborate their answers to get a better understanding for the problem (Denscombe, 2009).

The initial contact was done by phone where they interviewed persons got a brief description on the subject and a phone meeting was booked. Then an email was sent out with the questions that needed answering so that the person that was being interviewed was well prepared. When carrying out the interviews notes and voice recording were taken so an analysis of the material could be done afterwards. The questions that were asked were identical except the follow-up questions to get deeper understanding.

3.2.1 Selection of Respondents

The background material was compiled by a large amount of information from different sources. The material has been evaluated and analyzed based on the relevance of the question and the study's delimitations. This gives the study a broad and clear background information.

3.3 Reliability, Validity and Generalizability

To achieve as high level of credibility as possible, the case study and the selected group have been selected with great care. The aim has been to find a group with as much experience of both diesel engines and technical development as possible. Since the technology is relatively new, the selection of groups is limited. According to (Höst & et al., 2006) case studies are not generalizable. Validity is, according to Autumn, et.al (2006), the link between the investigated phenomenon and what is measured. By formulating well-defined questions and interviewing people who are well-informed and interested in the field that are investigated will lead to higher credibility.
By using literature and materials that are well-connected to the subject and questions, the validity is increased.

3.4 Ethical Considerations

The interviews address topics that may be sensitive to manufacturers as it concerns questions about technical solutions, prospects of the future and economics. Therefore, there is a trust from the participants to get sincere and responsive answers. Denscomde writes that the person getting interviewed is easily affected and to minimize that the questions were asked passive and neutral so that the answers are as valid as possible (Denscombe, 2009). Since data from the interviews can contain sensitive information, it has been said that all the information from the interviews are handled confidentially, but that the authors presenting the information relevant to the question and that the interviewees were highlighted with this information. It has been described for those who were interviewed that only the authors have access to the full interview material.

4 Results

4.1 Interviewees

In this chapter we will describe our interviews background and relevance to the subject of autonomous ships.

Yemao Man, is a Doctoral student within the division Maritime Human Factors and Navigation, Before Yemao joined Chalmers, He earned a Double Master's degree specializing in computer Science from Uppsala University and Software Engineering in Tongji University in China. Yemao Man previous experience within the area of autonomous ships Yemao has been working in a project called MUNIN, this was an EU project to research the possibility of autonomous unmanned vessels for intercontinental voyages. Yemao has also been involved in a Project called Lighthouse which focus on the development of autonomous ships over the world and what the shipping industry can learn from other industries such as aviation and car industry.

Henrik Tunfors has an extensive career of working as a legal adviser in different areas in the maritime industry. Henrik has a Master of Laws degree from Lund University. According to Henrik Tunfors he would summarise his working experience as a Senior advisor in the maritime field with a demonstrated history of working in the maritime domain, especially in public governance, international negotiations and legal issues. Also, a seasoned chairman of different working groups in the international area, the IMO. Strong professional skilled in Government, Maritime Safety, Inspection, International Shipping, and Safety Management System.

Monica Lundh is working as a scientist mostly, guiding doctoral candidates and around twenty percent teaching at Chalmers University of technology. Before she worked at Chalmers she started as an engine cadet and worked her way up, she sailed five years as a marine-engineer before accidently started working as an instructor in the simulator at Chalmers. After this she got an opportunity to start studying and made her thesis about the environment in the engine room and how the demand changes due to modern technology.

Margus Pöldman is traffic-chief on Trafikverket. He has a background as a captain working on many kinds of ships and a as ship inspector before he started working at Trafikverket in two different periods first as an operation manager then they divided that job and made it in to traffic-chief also which Margus is currently working as. He has also been on many seminaries and lectures about just autonomous ships.

4.1.1 Complications with Autonomous Ships

All interviewees had a lot of concerns regarding autonomous ships and how they would work in the future. Monica and Yemao said that the transition phase would be one of the more complicated once, when there are a lot of older ships still sailing and autonomous ships being launched. This transition phase will prove to be a challenge for all seafarers with the new rules that might be implemented. When the interviewees were asked about the ethical stand point of autonomous ships, Yemao responded regard to question number 10.

Would you fly in an airplane without a pilot? I know I wouldn't be one of the first people getting on.

Monica said regarding to question number 10.

During the transition phase there need to be clear regulations regarding who has the way of right and who must yield when an autonomous ship comes sailing.

This seems to be a major concern for the people that were interviewed, that without the right form of regulations and laws how will seafaring work, Henrik Tunfors who works for "Transportstyrelsen" and has a Master of Law degree said regarding to question number 4.

At the moment there are a lot of applicable laws and delegation for autonomous ships, after all its still a ship.

In May of 2018 IMO will start to work with other countries in London to find legal disputes regarding autonomous ships and write new laws if needed, this will be an ongoing progress until the year of 2020.

Yemao and Margus also mentioned regarding to question number 4.

International rules will take some time to be implemented but national laws will happen much quicker because it only concerns the country in question.

Monica also mentions complications with autonomous ships that are controlled from a shore-based operations site that are still in the control of human operators, as seen in the MUNIN project people choose to put in manual navigational inputs when not trusting the system to be fully autonomous. Monica also says to question number 6.

You would still have to have people ashore to oversee the ship and in the transition phase have people who must sail the ship ashore, in turn the vessel traffic service industry will have to change. But if you have a human factor in the system you will still have a form of wildcard.

The interviewees also state their concern as one of the biggest faults to be bandwidth and internet connectivity. It is normal to have bad to none existing network onboard ships while sailing over the Atlantic Ocean and this is something that can't happen, losing the internet service on an autonomous ship could mean no controllability as the overseer wouldn't know what is happening at the ongoing costal route or if any form of malfunction or alarm would appear. This could mean that during this window of time that the ship could experience a black out and must have people flied out or sailed to the ship to regain control.

Monica mentions the problems with alarms onboard the ship, she says regarding question number 9.

At the moment we are surveilling every possible reading onboard the ship with trends because we can, but we aren't sure what to do with it this data, we have the technology, but we don't really know what to do with it, how could we use this data with remote control of the different trends to have an earlier indication that something is about to go wrong and take care of the problem before it happens.

4.1.2 Security Onboard an Autonomous Ship

Security onboard autonomous ships is a big concern because you don't have people onboard the ship, this would mean that autonomous ships are an easy target for hijacking partly for stealing information and to take control of the ship. At the hands of hijackers, you never know what their intentions are, they might be interested in stealing the cargo or do acts of terrorism on a global scale.

Henrik also mentions to question 15.

It is interesting to see from an insurance stand point of view, how you would be able to insure an autonomous ship without people onboard.

With new technology comes new risks, this can be seen in the car industry as well with people being able to control cars from remote locations, if this was to happen to ship also the effects could be devastating. One thought that Monica mentioned to question number 15.

What would happen if a hijacked ship were to dump all its inert gas and then driven into an oil depo.

Then there is also the problem with AIS transmitting if people could hack this transmission according to Yemao.

Hacking the AIS transmission would be 50% of the job to take control of the ship. These problems would be immediate and wouldn't be easy to fix because you can't just send an update and have it fixed the next day, it would take a considerable amount of time and money.

4.1.3 Future Aspects

The future thoughts about autonomous ships only concerns one of the people we interviewed, Margus from Trafikverket. They have many small costal ferries that goes short distances along the coastline. His thoughts about autonomous ships today are low, the profit from sailing autonomous are small or close to zero.
He can see the possibility to use autonomous ferries on small routes, like a line ferry route but not on the more trafficked ones. Margus also had an interesting opinion to question number 13.

We can see the possibility to have an autonomous line ferry, but the problem remains, there is only one person maneuvering the ship onboard so why should we place that person ashore instead of keeping that person onboard.

One future aspect to think about is the cost of employees onboard the ships are only a small expense, compared to the profit it makes, when transporting large quantities of cargo. Monica says.

The employees are only about 3% of the total cost onboard a large container ship.

One big factor is also that the people that we have interviewed don't think that the current technology is up to the demands that companies want them to be able to sail fully autonomous and at the moment most companies are mostly doing it as test to see if it would be beneficial and then later implement it worldwide. Monica stated.

I don't believe autonomous ships will be fully functional during my life time and most likely come at a much later time.

But our interviewees also see positive aspects with autonomous ships in the future. They see the possibility to save on fuel which reduces the impact on the environment and removing the human error in accidents if the ship is sailing fully autonomous.

4.1.4 Summary Result

From the interviewees it can be understood that they are on the same page regarding autonomous ships in the perspective that it will take a lot of time and effort before they can be implemented in a worldwide setting. They are also in agreements that there are a lot of considerations with autonomous ships and a lot of problems that still must be addressed before autonomous ships are considered safe and able to sail together with other seafarers. They don't think that the cost of autonomous ships will be lower than it is today, but instead that the cost will increase with time as new technology for AI comes out. The interviewees are also uncertain if there will ever be fully autonomous ships, because the cost of having people onboard is quite small considering other aspects, such as fuel and ethical consideration that you would want someone to maneuver the ship for you and take care of the problems immediately if a problem would occur. There is also the question about how much money you would save in the long run if it is worth to sail fully autonomous with having to fly service crews out to ships when there are problems instead of just having crew onboard. All interviewees also had their concerns regarding internet connectivity and how it would work, if you are sailing across the Atlantic Ocean or just docking the ship with uptime and delay, this could be the factor for an accident. There is also the risk of cyber security threats and hijacking as well. They also think that the international regulations will slow things down due to that all members of IMO needs to accept the new law delegations before autonomous ships can sail on international waters, but national laws will most likely be approved much sooner allowing test beds for autonomous ships. From what the interviewees says the two main benefits of sailing autonomous is reduced risk of the human error and beneficial gains of the environment impact by reducing the fuel consumption.

5 Discussions

5.1 Method Discussion

During our studies to achieve as high level of credibility as possible we have used a case study with a selected group of people to interview, this will give us a good depth of data for the investigated subject. The study is based on a research characteristic, we think this is the best method to get our questions answered for this thesis. When the interviews were analyzed and summarized we noticed that there is a big concern with autonomous ships and their advancements in technology in our current society, the technology that we have today isn't up to the task. If we would have had a broader perspective on our research gathering, we might have gotten a broader perspective on the subject and a different answer.

5.1.1 Reliability, Validation and Generalizability

In this study we have interviewed four people with a connection to the subject, but none of our interviewees has been in the development of autonomous ships. The limited number of interviews makes so that the study cannot be generalized but only enlighten what a specific group thinks about the questions. If the amount of people interviewed had been greater we might have come to a different conclusion.

The reliability in the study is considered valid, because the persons interviewed are knowledgeable in the subject and have great knowledge about the problems with autonomous ships. If the selected people interviewed had been greater, then the results that we have gathered might have been different. Our efforts have been to try and find a group of people with much experience in maritime law, seafarers experience, research and autonomous ships, to achieve as high credibility as possible. A limiting factor about this subject is that it is relatively new and therefore it is hard to get valid response to our questions. The reliability is good because the questions in the interviews is limited and has a connection to the subject at hand. The material in the literature study is chosen with a strong connection to the questions and technology about autonomous ships.

5.1.2 Background Material

The material for the background information is chosen to give a broad and deep understanding about the subject. The literature is based on textbooks, scientific articles, newspaper articles and educational material. To not risk the reliability of the report has the material connected to newly launched autonomous ships been overlooked because there is a risk that the author might have a cooperate influence on the report.

Some parts of the material that has been used and referred to during the report comes from manufacturers and can be seen as non-dependent sources. The material contains descriptions that are relevant and is trustworthy because it is coming from the manufacturers. Because of this it is important to be aware of the materials origin and purpose to not be affected by the manufacturers view in the report, which can lead to lower credibility.

5.1.3 Interview

The interviews have been conducted over phone and in person, the initial contact has been done over phone or email to get a form of relationship and in turn to set up a meeting time and place to conduct the interview. Several of our respondents were researchers and high profiles in their companies making it hard to find a time when the interviews could be conducted. Before the interviews the research questions were sent out to the respondent to give them time to think about the questions. The interviews were carried out by phone at a later date, so the interviewees could develop their answers. The benefits of conducting an interview by phone or in person is that there less chance of misinterpretation of the questions and questions can be answered in a greater depth then if we would have conducted an email interview.

All the interviewees didn’t have Swedish as their native tongue and therefore the questions were written in both English and Swedish to give the persons interviewed the option to choose between the language they were most comfortable with. The language barrier between Swedish and English are considered great, but we view our knowledge about English to be good, so that it didn’t affect the end results.

5.1.4 Evaluation of Sources

The material that has been used in the background is based on independent sources, which has motivated us to use them. Articles with a connection to different companies researching autonomous ships, has been used as a support for the background. The material is valid and reliably because it comes from big companies with good knowledge about autonomous ships.

5.2 Result Discussion

The results in the study shows that an important factor for our interviewees is that the vison of autonomous ships is in general positive, but they also have their concerns about internet connection, transition phase and the law delegations for autonomous ships sailing in international waters will take some time to be put into effect. Based on our studies and research we have found that the advancements in technology is a big factor in pushing the development of autonomous ships forward. Shipping companies strives to always have the latest technology onboard their ships, therefore the developers of the technology for autonomous ships will have to try and meet the expectation of the buyers and push forward their technology.

5.2.1 Interviewees Thoughts on Autonomous Ships

The vision of autonomous ships is in general positive, our interviewees see autonomous ships as a new technology that should be developed and come out into the market and sail with other ships, they say that with the big concern about fuel prices and environmental effect done to the environment with pollution from ships that autonomous ships can help with this. The interviewees also mention that without people onboard there is a lower risk of the human factor with accidents, but as stated above the cost of having people onboard is very low considering other costs.

The interviewees that have been included in this report has a lot of experience in different fields, one of the persons we interviewed works for Trafikverket which have many small costal ferries. They are thinking about having autonomous ships on some of their smaller routes, but they think the technology needs to be developed and well sorted before they see a beneficial gain before implementing it on their ships. A reason for this is that they do not have the resources to develop that technology and they cannot have any interference with their tight schedule, that is why they uses reliable and well proven technology. There is no guarantee that new technology is successful in terms of function and that it achieves economic profitability.

5.2.2 Disadvantages with Autonomous Ships

Autonomous ships have many advantages but also some drawbacks. Our interviewees highlight that there are problems with the internet connection and the high prices of having a good and reliable connection. Autonomous ships use a very complex system with even more components and advanced machinery. Based on our knowledge this could lead to higher maintenance costs and the need for different expertise. A more advanced system needs more maintenance which can lead to more down time during the of troubleshooting and repairs. Another drawback is also that you do not have a crew onboard the ships that can solve the problem immediately but instead you must fly out a service crew to fix the problem.

5.2.3 Future Aspects

The focus on the environment and cost savings will still be a highly prioritized question when developing and operating an autonomous ship. The need for better satellite connection on the oceans will have to develop before a fully autonomous ship can operate. There will probably be more strict regulations for autonomous ships, so the shipyards and developers need to be able to handle and adapt to the new regulations.
The aspect of onboard security will have to developed, piracy is still a problem, so the ship designers needs to rethink ships designs so it will be harder to board and have a permanently mounted ship defense system to prevent boarding.

6. Conclusion

Based on the result from the interviews and our research we can conclude that the main question and sub question are answered as follow:

- The main challenges with sailing an autonomous ship are the internet connectivity, the technology does not meet the demands for sailing fully autonomous yet, the transition phase, law delegations, cyber security, piracy treats and the ethical considerations.

- The two main benefits with sailing an autonomous ship are the reduced risk of the human error and beneficial gains of the environment impact by reducing the fuel consumption.

For future research the authors think it would be interesting to investigate a shipping companies point of view when autonomous ships are in operation, because this study is mainly focused on the challenges and benefits from researchers point of view.

There can also be future research conducted on the beneficial gains from an economic point of view with sailing fully autonomous.

References

(Conference), E. (2007). *6th International Conference, EGOV 2007, Regensburg, Germany, September 3-7, 2007. Proceedings.* Springer.

al., H. e. (2017). *Utilization and Optimization of Diesel Generation for Maximum Renewable Energy Integration.* Australia: ICT University of Tasmania, Hobart.

Curley, R. (2012). *The Complete History of Ships and Boats: From Sails and Oars to Nuclear-Powered Vessels.* New York, NY 10010: Britannica Educational Publishing.

Daekeun, M., Deokhwan, C., Jinho, P., & Dongho, P. (2016). *Integrated Extension Alarm System for Machinery and Cargo Monitoring.* korea: Electro-Mechanical Research Institute, Hyundai Heavy Industries Co., Ltd., Ulsan, KOREA.

Denscombe, M. (2009). *Forskningshandboken : för småskaliga forskningsprojekt inom samhällsvetenskaperna.* Lund : Studentlitteratur, 2009.

DNV, G. (2011, 01). PERIODICALLY UNATTENDED MACHINERY SPACE. *part 6 chapter 3*. DNV.

Draffin, N. (2012, 06 01). *Bunker Fuel for Marine Engines.* Petrospot. Retrieved from https://ebookcentral.proquest.com/lib/chalmers/reader.action?docID=3385442&query=

Herdzik, J. (2013). *Problems of propulsion systems and main engines choice.*

Hills, R. L. (1989). *Power from steam: a history of the stationary steam engine.* Cambridge Univ. Press.

Housen-Couriel, D. (2016). *Cybersecurity threats to satellite communications: Towards a typology of state actor responses.* Israel: Elsevier Ltd.

Höst, M., & et al. (2006). *Att genomföra examensarbete.* Lund : Studentlitteratur, 2006.

IMO. (1994). *Human Environment and Transport Inspectorate - Ministry of Infrastructure and the Environment*. Retrieved from Human Environment and Transport Inspectorate - Ministry of Infrastructure and the Environment: http://imo.udhb.gov.tr/dosyam/EKLER/MSC-Circ.645.pdf

International Maritime Organization. (2004). *SOLAS : consolidated text of the International Convention for the Safety of Life at Sea, 1974, and its protocol of 1988: articles, annexes and certificates.* London: International Maritime Organization.

Jan, R. Ø., & Beate, K. (2009). Digital Communication Bandwidth requirements for Future e-Navigation Services. *European Journal of Navigation, Vol. 7, No. 1*.

Jinfen, Z., Xinping, Y., Xianqiao, C., Lingzhi, S., & Di, Z. (2012). *A novel approach for assistance with anti-collision decision making based on the International Regulations for Preventing Collisions at Sea.* china.

Kongsberg. (2014, March). *K-chief*. Retrieved from KongsBerg: https://www.km.kongsberg.com/ks/web/nokbg0397.nsf/AllWeb/FF4B7F8311CB5B5BC1257264005336F2/$file/K-Chief-brochure.pdf?OpenElement

KONGSBERG. (n.d.). *KONGSBERG*. Retrieved from https://www.km.kongsberg.com/ks/web/nokbg0240.nsf/AllWeb/597733F8A1B8C640C12580AC0049C134?OpenDocument

Kuiken, K. (2012). *Diesel Engines I.* Netherlands : Target Global Energy Training .

Kuiken, K. (2012). *DIESEL ENGINES II.* Onnen: Target Global Energy Training .

Kumar, S. (2015, 12 23). *Marine Insight*. Retrieved from Marine Insight: https://www.marineinsight.com/future-shipping/shipbuilding-technologies/

Lakshmi, A. (2017, december 6). *China's 'Smart' Ship Debuts in Shanghai*. Retrieved from MarineLink: https://www.marinelink.com/news/shanghai-debuts-chinas431886?utm_source=MT-ENews-2017-12-07&utm_medium=email&utm_campaign=MT-ENews

Latarche, M. (2017, 06 12). *ShipInsight*. Retrieved from https://shipinsight.com/explaining-the-types-of-fuel-used-on-ships/

MAN Diesel & Turbo. (n.d.). *Hybrid Propulsion Flexibility and maximum efficiency optimally combined.* MAN Diesel & Turbo. Retrieved from Marine Man diesel turbo: https://marine.mandieselturbo.com/docs/default-source/shopwaredocumentsarchive/hybrid-propulsion.pdf?sfvrsn=4

Mohit. (2016, 07 21). *Marine Insight*. Retrieved from Marine Insight: https://www.marineinsight.com/maritime-law/what-are-the-essential-requirements-for-unattended-machinery-space-ums-ship/

Nationalencyklopedin. (2010). *Nationalencyklopedin*. Retrieved from Nationalencyklopedin: https://www.ne.se/uppslagsverk/encyklopedi/l%C3%A5ng/artificiell-intelligens

Network, M. U., & Munin. (n.d.). *Munin*. Retrieved from Munin: http://www.unmanned-ship.org/munin/about/

Phaneuf, B. A. (2016). *Kongsberg*. Retrieved from Kongsberg: https://www.km.kongsberg.com/ks/web/nokbg0238.nsf/AllWeb/65865972888D25FAC125805E00281D50?OpenDocument

Pike, D. (2017, 01 04). *maritimejournal*. Retrieved from maritimejourna: http://www.maritimejournal.com/news101/industry-news/automated-fully-electric-ferries

Plass, S., Clazzer, F., Fritz, B., Yasrine, I., & Maurizio, M. (2014). *Maritime communications – Identifying current and future satellite requirements & technologies* . Italien.

Prince, R. (2017, 10). *ProQuest*. Retrieved from ProQuest: https://search.proquest.com/docview/1949290662?pq-origsite=summon

Rolls Royce. (2016, 10 18). *Rolls Royce*. Retrieved from Rolls Royce: https://www.rolls-royce.com/media/press-releases/yr-2016/18-10-2016-rr-to-supply-first-automatic-crossing-system-to-norwegian-ferry-company-fjord1.aspx

Torstein, I. B. (2016). *Scenario- and Optimization- Based Control of Marine Electric Power Systems.* Norwegian University of Science and Technology.

Trafikverket. (2014, 01 29). *Trafikverket*. Retrieved from Färjerderiet: https://www.trafikverket.se/farjerederiet/om-farjerederiet/vara-farjor/Vara-farjor/Ada/

Valkeejärvi, K. (2006). *The ship's electrical network, engine control and automation.* Wärtsilä Corporation.

Wang, M., Li Hong, S., Miao, Q., & Bian Guang, R. (2014). *Intelligent control algorithm for ship dynamic positioning.* The Journal of Polish Academy of Sciences.

WIJNEN, P. (2017, 05 29). *norwaytoday*. Retrieved from norwaytoday: http://norwaytoday.info/finance/fully-electrical-ferry-built-fjord1/

Index

Appendix 1. Regulations

Appendix I

Regulation 26 General regulations regarding machinery installations

1 The machinery, boilers and other pressure vessels, associated piping systems and fittings shall be of a design and construction adequate for the service for which they are intended and shall be so installed and protected as to reduce to a minimum any danger to persons on board, due regard being paid to moving parts, hot surfaces and other hazards. The design shall have regard to materials used in construction, the purpose for which the equipment is intended, the working conditions to which it will be subjected and the environmental conditions on board.*

2 The Administration shall give special consideration to the reliability of single essential propulsion components and may require a separate source of propulsion power sufficient to give the ship a navigable speed, especially in the case of unconventional arrangements.

3 Means shall be provided whereby normal operation of propulsion machinery can be sustained or restored even though one of the essential auxiliaries becomes inoperative. Special consideration shall be given to the malfunctioning of:

1. *A generating set which serves as a main source of electrical power;*
2. *The sources of steam supply;*
3. *The boiler feed water systems;*
4. *The fuel oil supply systems for boilers or engines;{*
5. *The sources of lubricating oil pressure;*
6. *The sources of water pressure; Part C: Machinery installations Regulations 25-10, 26 * Refer to MSC/Circ. 834, Guidelines for engine-room lay-out, design and arrangement. { Refer to MSC/Circ.647, Guidelines to minimize leakage from flammable liquid systems, as supplemented by MSC/Circ. 851, Guidelines on engine-room oil fuel systems. 107 .*
7. *A condensate pump and the arrangements to maintain vacuum in condensers;*
8. *The mechanical air supply for boilers;*
9. *An air compressor and receiver for starting or control purposes;*
10. *The hydraulic, pneumatic or electrical means for control in main propulsion machinery including controllable pitch propellers. However, the Administration, having regard to overall safety considerations, may accept a partial reduction in propulsion capability from normal operation.*

4 *Means shall be provided to ensure that the machinery can be brought into operation from the dead ship condition without external aid.*

5 *All boilers, all parts of machinery, all steam, hydraulic, pneumatic and other systems and their associated fittings which are under internal pressure shall be subjected to appropriate tests including a pressure test before being put into service for the first time.*

6 *Main propulsion machinery and all auxiliary machinery essential to the propulsion and the safety of the ship shall, as fitted in the ship, be designed to operate when the ship is upright and when inclined at any angle of list up to and including 158 either way under static conditions and 22.58 under dynamic conditions (rolling) either way and simultaneously inclined dynamically (pitching) 7.58 by bow or stern. The Administration may permit deviation from these angles, taking into consideration the type, size and service conditions of the ship.*

7 *Provision shall be made to facilitate cleaning, inspection and maintenance of main propulsion and auxiliary machinery including boilers and pressure vessels.*

8 *Special consideration shall be given to the design, construction and installation of propulsion machinery systems so that any mode of their vibrations shall not cause undue stresses in this machinery in the normal operating ranges.*

9 *Non-metallic expansion joints in piping systems, if located in a system which penetrates the ship's side and both the penetration and the nonmetallic expansion joint are located below the deepest load waterline, shall be inspected as part of the surveys prescribed in regulation I/10(a) and replaced as necessary, or at an interval recommended by the manufacturer.*

10 *Operating and maintenance instructions and engineering drawings for ship machinery and equipment essential to the safe operation of the ship shall be written in a language understandable by those officers and crew members who are required to understand such information in the performance of their duties*

11 *Location and arrangement of vent pipes for fuel oil service, settling and lubrication oil tanks shall be such that in the event of a broken vent pipe this shall not directly lead to the risk of ingress of seawater splashes or rainwater. Two fuel oil service tanks for each type of fuel used on board necessary for propulsion and vital systems or equivalent arrangements shall be provided on each new ship, with a capacity of at least 8 h at maximum continuous rating of the propulsion plant and normal operating load at sea of the generator plant.* This paragraph applies only to ships constructed on or after 1 July 1998.*

Appendix II

Regulation 40 General Electric installations

1 ***1*** *Electrical installations shall be such that:*

1. *All electrical auxiliary services necessary for maintaining the ship in normal operational and habitable conditions will be ensured without recourse to the emergency source of electrical power; .*
2. *Electrical services essential for safety will be ensured under various emergency conditions; and .*
3. *The safety of passengers, crew and ship from electrical hazards will be ensured.*

2 *The Administration shall take appropriate steps to ensure uniformity in the implementation and application of the provisions of this part in respect of electrical installations.*

Appendix III

Regulation 46 General

Additional requirements for periodically unattended machinery spaces

1 *The arrangements provided shall be such as to ensure that the safety of the ship in all sailing conditions, including manoeuvring, is equivalent to that of a ship having the machinery spaces manned.*

2 *Measures shall be taken to the satisfaction of the Administration to ensure that the equipment is functioning in a reliable manner and that satisfactory arrangements are made for regular inspections and routine tests to ensure continuous reliable operation.*

Every ship shall be provided with documentary evidence, to the satisfaction of the Administration, of its fitness to operate with periodically unattended machinery spaces.

Appendix 2. Interview questions

1. What are the most immediate problems that need to be addressed before ships can become fully autonomous?

2. What are the biggest challenges for someone that is developing autonomous ships?

3. Is there any new legislation for autonomous ships that has been created as year 2018?

4. Do you expect the legislation for autonomous ships to change in the next six months to a year or two?

5. What are the most important things you'd like to be see accomplish in the first 30, 60, and 90 days of the ship going fully autonomous?

6. What would you expect the revenue of autonomous ships be over the first 12 months?

7. What would you say are the two greatest investments for an autonomous ships propulsion system?

8. What do you think would be the two main benefits to sail an autonomous ship?

9. What do you think IMO and other law delegations will write about autonomous ships?

10. Do you believe that there is an ethical question with autonomous ships?

11. Do you work for a shipping company? Or in some other field regarding seafarers.

12. What is your position in the company?

13. Does your company have any plans to launch or build an autonomous ship?

14. what would you say are the two biggest gains/achievements/profits with autonomous ships?

15. What are your concerns regarding hijacking and security aboard autonomous ships?